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Peter Baker

**THE ROLE, DESIGN AND OPERATION OF
DISTRIBUTION CENTRES IN AGILE
SUPPLY CHAINS**

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PETER BAKER

**THE ROLE, DESIGN AND OPERATION OF DISTRIBUTION
CENTRES IN AGILE SUPPLY CHAINS**

SUPERVISOR: Prof. MARTIN CHRISTOPHER

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Doctor of Philosophy**

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Abstract

The aim of this research is to explore the role of distribution centres (DCs) in agile supply chains, together with how they should be designed, operated and their performances measured within this context. The research is based, first of all, on a survey to ascertain the current situation, and then a series of case studies of international supply chains, DC designs, DC operations, and warehouse automation projects. The techniques used include questionnaires, semi-structured interviews, quantitative measures where appropriate and qualitative measures based on 5-point Likert scales. A number of constructs are used, particularly from supply chain agility and manufacturing agility literature, and these are refined and extended to form the basis for the research.

The findings indicate that a prime role of distribution centres, particularly in terms of inventory-holding, is consistent with the decoupling point concept. Further roles for distribution centres in agile supply chains include cross-docking, postponement activities, and returns.

The research identifies five types of agility, namely volume, time, unit quantity, presentation and information. The responses to these different types can then be categorised according to the combination of levels (i.e. supply chain, business unit, distribution network, and distribution centre), by the type of resource used (i.e. land / building, equipment, staff, and process / systems), and by how these are deployed (i.e. extra capacity, additional resources when needed, and flexible resources). Agility measurement can be undertaken using the categories of range, mobility and uniformity.

With markets becoming more volatile, agility can offer a key source of competitive advantage. However, warehouses are by their nature long-term fixed assets and therefore difficult to incorporate into an agile strategy. The series of frameworks developed during this research begins to address this important area and thus forms a basis for further research as well as providing some initial frameworks to assist practitioners.

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List of Publications Submitted

1. Baker, P. (2004). Aligning distribution center operations to supply chain strategy. *International Journal of Logistics Management*, 15(1), p. 111-123.
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3. Baker, P. (2006). Designing distribution centres for agile supply chains. *International Journal of Logistics: Research & Applications*, 9(3), p. 207-221.
4. Baker, P. (2007).The design and operation of distribution centres within agile supply chains. *International Journal of Production Economics*, doi: 10.1016/j.ijpe.2006.09.019.
5. Baker, P. and Halim, Z. (2007). An exploration of warehouse automation implementations: cost, service and flexibility issues. *Supply Chain Management: An International Journal*, 12(2), p. 129-138.

Declarations

PhD by Publication (under Regulation 39.6)

None of the publications contained in this submission for the award of PhD under Regulation 39.6 has been presented for any other academic or professional distinction.

Five papers published between 2004 and 2007 are contained in this submission. Four papers are sole authored and are my own work. One paper is co-authored with Zaheed Halim. For the latter, my contribution has been agreed as being 60%.

Confirmation of percentage contribution for Paper 5

Copy email dated 26th November 2006:

From: Zaheed Halim [mailto:leen-ipe@sust.edu]

Sent: 26 November 2006 04:57

To: Baker, Peter

Subject: Paper submitted to SCMIJ

Peter,

The journal paper that we have written jointly in SCM:IJ should have a contribution split as 60 %(PB) / 40 %(ZH).

Best Regards, Zaheed

Zaheed Halim

Assistant Professor

Department of Industrial & Production Engineering

Shah Jalal University of Science and Technology

Sylhet, Bangladesh - 3114

Phone: 880-821-713491,714479,717850 Ext-168

Fax: 880-821-715257

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List of Abbreviations

3PL	Third party logistics
AGV	Automated guided vehicle
AS/RS	Automated storage and retrieval system
DC	Distribution centre
DEA	Data envelopment analysis
EDI	Electronic data interchange
ERP	Enterprise resource planning
KPI	Key performance indicator
OTIF	On time in full
RDT	Radio data terminal
SCP	Supply chain planning
SKU	Stock-keeping unit
UK	United Kingdom
US, USA	United States of America
WMS	Warehouse management system

1 INTRODUCTION

1.1 Background to the research

The research described in this thesis is concerned with a currently rather neglected area of supply chains, namely the warehouses that act as key nodes in the movement of goods to the end consumers. This feeling of neglect is apparent for example in the opening sentence of a book by Frazelle (2002a, p. 1):

“With so many attempts to eliminate inventory and warehousing in the supply chain, why should you read a book on warehousing?”

A similar feeling is expressed by Higginson and Bookbinder (2005, p. 67), bemoaning a neglect of both transportation and warehousing:

“That is, analysts have put all their attention into designing the perfect network, and have worried too little about managing the flows of products between nodes. It could be argued that Distribution Centres (DCs) are another forgotten area.”

However, it is not clear why warehouses should be considered a forgotten area, as they appear to be vital components of supply chains, both in terms of costs and service. A survey in Europe estimated that warehousing accounts for 24% of logistics costs, whilst the inventory within them accounts for a further 13% (European Logistics Association/AT Kearney, 2004). A similar survey in the USA estimated the figures at 24% and 22% respectively (Establish/Davis, 2005). As regards service, warehouses are normally the nodes in the supply chain where customer orders are assembled and despatched and are therefore critical to the success or failure of many supply chains (Frazelle, 2002b). Customer service failings at the warehouse level can have significant impacts on companies in terms of sales and profits, for example with the introduction of Sainsbury’s ‘fulfilment factories’, where a lowering of on-shelf availability affected sales and market share (Sainsbury, 2004), and in terms of delivery failures, for example the bad publicity surrounding the Toys R Us failure to fulfil their Christmas delivery promises, arising from difficulties in commissioning their Memphis distribution centre as well as numerous associated business issues (Kover, 2000). On the other hand, warehouse successes are often seen as a key to competitive advantage, as in the case of Wal-Mart, who significantly improved the flow of goods through the supply chain by introducing cross-docking techniques in their warehouses (Stalk *et al.*, 1992).

Owing to this apparent paradox between some writers regarding warehouses as being a forgotten area and the apparent importance of warehouses in modern supply chains, a key driver for this research has been to explore the current role of warehouses, particularly as regards whether and how they fit with modern supply chain strategies.

A common classification of supply chain strategies is based on Fisher (1997), who differentiated between the types of supply chain required for functional products (i.e. with predictable demand, long product life cycles, low variety and long lead times)

and for innovative products (i.e. those with the opposite characteristics). He termed the required supply chains as efficient and responsive respectively. These broadly correspond to lean supply chains, where cost is the order winner, and agile supply chains, where service is the order winner, as described by Mason-Jones *et al.* (2000). A similar classification is used by Gattorna (2006), although the type of customer is the focus rather than the product, as an individual product may be subject to a number of different customer types (and, hence, different 'order winners').

Much of traditional supply chain thinking has been concerned with cost efficiency (for example, with one such reference dating back to 1844, as mentioned in Langley, 1992) but with many markets now becoming increasingly volatile (Weber, 2002), a key area of recent interest has been how to construct supply chains to be agile in nature. As explained later in Chapter 2, whilst there has been considerable literature on supply chain agility, this has not extended into the subject of distribution centres. Thus, the exploration of distribution centres in agile supply chains has been adopted as the focus of this research.

1.2 Definitions

Warehouses and distribution centres:

Although the terms 'warehouse' and 'distribution centre' are often used interchangeably, there are a number of different views on their precise meaning. One view is that warehouses are primarily for storing goods, whilst distribution centres are for moving goods through in a rapid manner (as noted by Hatton, 1990). This is supported, for example, by Dawe (1995, p. 102), who states that:

“Warehouses handle most products in four cycles..(receive, store, pick, and ship)..; DCs handle most products in two: receive and ship.”

De Koster *et al.* (2007, p.482), draw a different distinction, aligning the term 'distribution centre' more closely to the role of storage:

Warehouses.. “are commonly used for storing or buffering products (raw materials, goods-in-process, finished products) at and between points of origin and points of consumption. The term 'warehouse' is used if the main function is buffering and storage. If additionally distribution is a main function, the term 'distribution centre' is commonly used, whereas 'transshipment', 'cross-dock', or 'platform' centre are often used if storage hardly plays a role”

Rouwenhorst *et al.* (2000, p.515) use the term 'warehouse' in a much wider sense to encompass all types of nodes in a distribution network, stating:

“The efficiency and effectiveness in any distribution network in turn is largely determined by the operation of the nodes in such a network i.e. the warehouses”

Frazelle (2002a) follows this wide use of the term ‘warehouse’ to encompass a variety of roles, of which the ‘distribution centre’ is just one. Thus, he lists these roles as:

- Raw material and component warehouses
- Work-in-process warehouses
- Finished goods warehouses
- Distribution warehouses / centres
- Fulfilment warehouses / centres
- Local warehouses
- Value-added service warehouses

Within this list, Frazelle (2002a, p. 3) defines the role of “distribution warehouses / centres” as being to:

“Accumulate and consolidate products from various points of manufacture within a single firm, or from several firms, for combined shipment to common customers....Product movement may be typified by full pallets or cases in and full cases or broken case quantities out”

Higginson and Bookbinder (2005) provide a list of roles specifically for distribution centres, as follows:

- Make-bulk / break-bulk consolidation centre
- Cross-dock
- Transshipment facility
- Assembly facility
- Product-fulfilment centre
- Returned goods
- Miscellaneous other roles

This list goes slightly wider than that of Frazelle (2002a) in that it includes activities such as fulfilment (i.e. responding to orders from the final consumer) and value-added services within the definition of distribution centre.

For the purposes of this research, the term ‘warehouse’ is used as a generic term to cover all of the roles listed by Frazelle (2002a) above. It is however difficult to use the term ‘distribution centre’ solely as described by Frazelle (2002a), for, as he recognizes, a single facility may encompass a number of these roles. In fact, a remark by Higginson and Bookbinder (2005, p.71) applies equally to both lists, namely:

“Our definitions of these roles are misleadingly clear”

Within this research, the focus is commonly taken as being the facility (i.e. a building on a single site) and thus a combination of the above roles is likely to be included. The term ‘distribution centre’ is therefore taken to include those warehouses acting as nodes on the outward supply chain (i.e. post manufacture), and may encompass any

combination of finished goods warehouses, fulfilment warehouses, local centres or value-added service warehouses (from the list by Frazelle, 2002a) and any of the roles listed by Higginson and Bookbinder (2005).

Supply chain:

There tends to be broader consensus on the definition of 'supply chain'. For example, Stevens (1989, p.3), defined it as:

"The supply chain...is the connected series of activities which is concerned with planning, co-ordinating and controlling material, parts and finished goods from suppliers to the customer"

Another definition places more emphasis on the organisations in the chain and adds returns to the concept, as in the following definition by Harrison and van Hoek (2005, p.7):

"A supply chain is a group of partners who collectively convert a basic commodity (upstream) into a finished product (downstream) that is valued by end-customers, and who manage returns at each stage"

One definition, by Chopra and Meindl (2007, p. 3), specifically includes warehouses in the definition:

"A *supply chain* consists of all parties involved, directly or indirectly, in fulfilling a customer request. The supply chain includes not only manufacturers and suppliers, but also transporters, warehouses, retailers, and even customers themselves"

There has been further discussion as to whether, for example, the word 'demand' is more appropriate than 'supply' (e.g. Rainbird, 2004) and whether 'network' is more appropriate than 'chain' (e.g. as noted by Ellram, 1991). However, for the purposes of this research, the term supply chain is used, as characterized by the above definitions and, in particular, the definition by Chopra and Meindel (2007) is adopted.

Agility and flexibility:

As noted by Stratton and Warburton (2003) there have been a range of definitions of supply chain agility and many of these reflect the aspirational nature of the concept. For example, Bal *et al.* (1999, p.75) give the following definition:

"Agility is the basis for achieving competitive advantage in changing market conditions"

Christopher (2000, p. 37) expands on such definitions to provide some of the key elements that should be in place to achieve supply chain agility:

"Agility is a business-wide capability that embraces organizational structures, information systems, logistics processes, and, in particular, mindsets. A key characteristic of an agile organization is flexibility"

The term flexibility is introduced within this definition. Although ‘agility’ and ‘flexibility’ are often used interchangeably, the term ‘agility’ is more normally used at a higher (e.g. business wide) level whereas ‘flexibility’ tends to be used at a lower (e.g. operational) level. In general, agility is used in a customer facing sense (i.e. in an external context) as the ability to respond and benefit from market changes. An analysis of a number of supply chain and manufacturing papers in Figure 1-1 supports this. However, the term ‘flexibility’ is used in both an external and an internal (i.e. operational) context, particularly in manufacturing literature and especially where only that term is used.

Paper	Terms used	Literature base	Agility: external context	Agility: internal context	Flexibility: external context	Flexibility: internal context
Christopher (2000)	A, F	S.C.	✓			✓
Christopher & Towill (2002)	A, F	S.C.	✓			*
Herer <i>et al.</i> (2002)	A, F	S.C.	✓			✓
Lin <i>et al.</i> (2006)	A, F	S.C.	✓			*
Prater <i>et al.</i> (2001)	A, F	S.C.	✓			*
van Hoek (2001)	A, F	S.C.	✓			✓
Weber (2002)	A, F	S.C.	✓			*
Gunasekaran (1999)	A, F	Mfg	✓			*
Sharifi & Zhang (1999)	A, F	Mfg	✓			*
Yao & Carlson (2003)	A, F	Mfg	✓			*
Yusuf <i>et al.</i> (1999)	A, F	Mfg	✓			*
Bal <i>et al.</i> (1999)	A	S.C.	✓			
Etienne (2005)	A	S.C.	✓			
Power <i>et al.</i> (2001)	A	S.C.	✓			
Stratton & Warburton (2003)	A	S.C.	✓			
Towill & Christopher (2002)	A	S.C.	✓			
Maskell (2001)	A	Mfg	✓			
Sharp <i>et al.</i> (1999)	A	Mfg	✓			
Hyun & Ahn (1992)	F	Mfg			✓	✓
Koste & Malhotra (1999)	F	Mfg			✓	✓
Upton (1994)	F	Mfg			✓	✓

Key

Terms used: A = agility; F = flexibility

Literature base: Mfg = manufacturing; S.C. = supply chain

Symbols: ✓ = term is used in context shown; * = flexibility is not clearly defined, but it is used as one component of agility.

Table 1-1 Use of the terms ‘agility’ and ‘flexibility’ in the literature

Within this thesis, it has been decided to use the term ‘agility’ in a business-wide and external facing context and to use the term ‘flexibility’ at an operational and internal facing context.

Capability and competence:

There is a similar overlap in the literature in the use of the terms ‘capability’ and ‘competence’. For example, Upton (1994, p. 75) clearly uses the term ‘capability’ in an internal context, as he states “it is important to distinguish the *capability* of being flexible from the competitive need it is intended to match or the customer related advantage derived from it”.

On the other hand, Zhang *et al.* (2002, p. 562) emphasise the external context of capabilities: “The internal dimensions are competences such as machining and routing flexibilities that provide the firm with an expanded set of abilities. These competences become the foundation for external, customer-facing, capabilities such as product mix flexibility and volume flexibility”. This wider view of ‘capabilities’, in comparison to ‘competences’, is also supported by Morash *et al.* (1996).

Within this thesis, the overall distinction drawn by Zhang *et al.* (2002) is adopted.

Automation:

A particular aspect of this research is the role of automation within DC agility and the following definition from Rowley (2000, p.38) has been adopted:

“The direct control of handling equipment producing movement and storage of loads without the need for operators or drivers”

This definition therefore includes equipment such as conveyors, sorters, automated storage and retrieval systems (AS/RS) and automated guided vehicles (AGVs), but excludes technology aids to operators, such as radio data terminals (RDTs) and voice picking technology.

1.3 Summary of definitions

The definitions used in this paper may be summarised as follows:

- *Warehouse:* A facility acting as a node in a supply chain, including for example raw material / component warehouses, work-in-process warehouses, finished goods warehouses, distribution warehouses / centres, fulfilment warehouses / centres, local warehouses and value-added service warehouses.
- *Distribution centre:* A facility acting as a node in the outbound supply chain (i.e. post manufacture), including for example finished goods warehouses, distribution warehouses, fulfilment warehouses / centres, local warehouses, value-added service warehouses, make-bulk / break-bulk consolidation centres, cross-dock centres, transshipment centres, assembly facilities, and returned goods centres.
- *Supply chain:* “A *supply chain* consists of all parties involved, directly or indirectly, in fulfilling a customer request. The supply chain includes not only manufacturers and suppliers, but also transporters, warehouses, retailers, and even customers themselves” (Chopra and Meindl, 2007, p.3).

- *Agility*: “Agility is a business-wide capability that embraces organizational structures, information systems, logistics processes, and, in particular, mindsets. A key characteristic of an agile organization is flexibility” (Christopher, 2000, p. 37).
- *Flexibility*: The ability to respond at an operational level.
- *Capability*: An external dimension that provides a firm with an expanded, customer-facing, ability.
- *Competence*: An internal dimension that provides a firm with an expanded operational ability.
- *Automation*: “The direct control of handling equipment producing movement and storage of loads without the need for operators or drivers” (Rowley, 2000, p.38).

2 THE RESEARCH GAP

2.1 The development of supply chain management

The term 'supply chain management' dates from the 1980s and has been attributed, in its popular sense, to Oliver and Webber (1982), as per Giannakis *et al.* (2004). It developed from the subject of logistics and has been characterized by the increasing levels of organisational integration that have been proposed. Stevens (1989) described four stages in a firm's development towards an integrated supply chain:

- Baseline
- Functional integration
- Internal integration
- External integration

The baseline position is characterized by companies vesting responsibility in individual departments, and thus warehousing would tend to be important in one or more of these areas. Functional integration involved bringing together, for example, all the departments concerned with the outward flow of goods. This period, generally considered to be around the 1950s and 1960s, recognized the need for an integrated distribution management structure (La Londe *et al.*, 1970). Many of the theories were centred on the total systems concept and total cost analysis (Ballou, 1987). For example, this involved calculating trade-offs between transport, inventory, and warehousing costs. The study of warehousing thus remained very relevant within this context.

The next stage of internal integration involved both supply and demand along the company's own supply chain, including for example marketing, purchasing, manufacturing and distribution. The focus therefore switched to how all of these departments could work together in an integrated manner. It was suggested that the total cost approach should be superseded by a total profit approach (Poist, 1974), whilst customer service levels, such as lead times, were now viewed as negotiable rather than being fixed criteria that had to be met (Houlihan, 1987).

The final stage, of external integration, is the essence of the supply chain management concept and involves integration with suppliers, customers and other parties in the supply chain. The degree of external integration has been shown to be strongly associated with high performance levels (Frohlich and Westbrook, 2001). A key element of this has been the substitution of information for inventory (Christopher, 1998) and thus the perceived role of warehouses has diminished, as well as the focus turning to organisational and information aspects of the supply chain.

2.2 Supply chain strategies

Although there is no universally accepted classification of supply chain strategies, a common distinction that is made is between lean and agile strategies, as described in Chapter 1 in relation to Fisher (1997), Mason-Jones *et al.* (2000), and Gattorna (2006).

The lean concept is primarily focused on the elimination of waste, such as excess inventory and resources, whilst the agile concept is concerned more with a rapid response to market opportunities. A lean strategy thus tends to be appropriate in steady state markets where cost is the 'order winner', whereas an agile strategy is more likely to be appropriate in a volatile market and where service is the 'order winner' (Mason-Jones *et al.*, 2000).

These two types of strategies are not necessarily mutually exclusive. Christopher and Towill (2001) explored a number of 'leagile' strategies, such as using lean concepts for fast moving products and agile concepts for slow moving lines, or lean for base demand and agile for surge demand. Another technique they described was to use inventory at a decoupling point to act as a buffer between a steady-state 'lean' upstream supply chain that would be driven by forecasts and a volatile 'agile' downstream supply chain that would be driven by actual customer orders.

Christopher *et al.* (2006) went on to develop a four-way taxonomy based on supply characteristics (i.e. short or long lead time) and demand characteristics (i.e. predictable and unpredictable demand). This taxonomy gave two situations where lean pipelines would be appropriate (i.e. both with predictable demand), one where an agile pipeline would be best suited (i.e. short lead time and unpredictable demand), and one where a leagile, also called a postponement, pipeline should be used (i.e. long lead time and unpredictable demand).

Following the original taxonomy of Fisher (1997), there has been increasing recognition that the distinction between lean and agile strategies should be based primarily on customer, rather than product, characteristics (e.g. Godsell *et al.*, 2006). Similarly, Gattorna (2006) suggests a segmentation based on buying behaviour, underpinned by the appropriate subcultures within the firm.

Although the distinction between, and the combinations of, lean and agile strategies have become more sophisticated, these two types of strategy remain the two main components of modern supply chain thinking. Interestingly, inventory has often been viewed as being largely incompatible with both of these two main types of strategy. Within the lean concept, inventory is regarded as one of the seven wastes (or 'muda') that need to be eliminated (Womack and Jones, 1996). Similarly, within the agile concept, the minimisation of inventory is regarded as being necessary to aid time compression and responsiveness to changing market conditions (Mason-Jones and Towill, 1999). This also tends to obviate the perceived need for warehouses, for which the storage of inventory is regarded as being a prime function.

2.3 Supply chain agility

Although warehouses may be designed with a number of objectives in mind, overall cost minimisation (for a given service level) is the normal determinant that is used (e.g. as per the various warehouse design optimization techniques researched by Ashayeri and Gelders, 1985). This tends to fit with the lean supply chain concept. Supply chain agility, on the other hand, requires a different approach to warehouse design and operation that may involve, for example, resources that are significantly underutilised in order to provide the required responsiveness. One example from the

literature is the Zara distribution centre at La Coruna, which is designed to work at well below capacity so that it can handle the peak demands when they do occur (Ferdows *et al.*, 2002). The research in this thesis has therefore been focused on warehousing within agile supply chains, as this area has not been so well covered in traditional warehousing literature (as will be discussed later in this chapter).

Supply chain agility has its origins in manufacturing flexibility (Aitken *et al.*, 2002) but the original manufacturing concepts have now been expanded to encompass a much wider management capability to be able to respond to dynamic and turbulent markets (van Hoek *et al.*, 2001). Indeed, agility involves not only responding to market changes but also gaining competitive advantage from such volatility (Sharifi and Zhang, 1999). In order to achieve this goal, companies require flexible capabilities in many areas, such as new product development, manufacturing, and logistics (Zhang *et al.*, 2002), and thus supply chain agility is an important integrative element within this management concept.

The literature on agility is largely at the theory building stage. Giachetti *et al.* (2003) note that, whilst the literature on flexibility is now sufficiently mature to transition to empirical research on actual measures, the agility literature still needs to define those measures.

Although there have been many papers written on the subject of supply chain agility, most of these have concentrated on the organisational aspects. This is unsurprising considering the development of the supply chain management concept, outlined earlier, in which external integration is seen as key goal. For example, this area is well explored in an audit of agile capabilities in the supply chain by van Hoek *et al.* (2001), which examined what is needed to move from a traditional organisation to an agile business approach, under the headings of process integration, virtual integration, network integration and customer sensitivity.

Although distribution centres have not been the focus of supply chain agility literature, there have been a number of themes that can be identified that have implications in terms of their design and operation. These may be grouped together under the following headings:

Inventory holdings: The true cost of inventory holding has been increasingly recognized in recent years as including, for example, the risk of obsolescence, stock deterioration, stock losses and insurance (Christopher, 1998). However, in terms of agility, it is the impact on responsiveness that is regarded as a key constraint. For example, Etienne (2005) examined such factors as speed to market for new products, feedback time for quality issues, and responsiveness to market niches, and concluded that “inventory is a net destroyer of supply chain responsiveness” (p.63). In agile supply chains, inventory tends to be replaced by the use of information and is thus held at few echelons, if at all (van Hoek *et al.*, 2001). Goods are seen as passing rapidly through the supply chain so that firms can respond rapidly and exploit any changes in market demand (Christopher and Towill, 2001). As noted earlier however, there is a role for inventory in agility literature in terms of ‘decoupling points’, which are used as a buffer to separate upstream lean operations from downstream agile responses to the market. It is recognised that high levels of product

availability are imperative to satisfy volatile markets (Childerhouse and Towill, 2000) and this implies a need for holding inventory. This particularly applies when there is a lead time gap: i.e. when the supply lead time is greater than the demand lead time (Harrison and van Hoek, 2005). The increasing level of global sourcing can in fact be associated with lengthy and uncertain international pipelines, and thus to a need for higher inventories (Lowson, 2002). There is thus some ambivalence in the agility literature as to whether and, at what level, inventory is required.

Customer lead times: In agile supply chains, short lead times to the customer are regarded as essential to be able to respond to variable customer demands and exploit market opportunities immediately. This is a key component of service, which is regarded as being the 'market winner' in such situations (Mason-Jones *et al.*, 2000). Distribution centres therefore need to be able to satisfy customer orders rapidly, whether from their own inventory or from other sources. They do however also need to be able to provide a range of lead times, in accordance with the growing realisation that a 'one-size-fits-all' supply chain is not appropriate in many situations.

Cross docking: One technique for moving goods quickly through the nodes of a supply chain is that of cross-docking. This is where goods are transferred immediately from arriving vehicles to despatch vehicles without being placed into storage. Thus, the goods are transferred directly from the receiving dock to the shipping dock with the minimum of dwell time in between (Apte and Viswanathan, 2000). Goods may arrive for cross-docking from distribution centres holding central inventories of slow moving goods (Bowersox *et al.*, 1999) or from distribution centres at the same echelon level in the supply chain (Herer *et al.*, 2002). In the case of the latter, goods may be held as a common 'virtual inventory' across a number of distribution centres and then repositioned in response to customer demands. Cross docking and in-transit merging (where different goods are brought together to form one delivery to a customer) are thus seen as possible operational techniques at distribution centres within agile supply chains (van Hoek, 2001).

Postponement: This may take the guise of 'time postponement', when products are shipped to order, 'logistics postponement', where goods are stored at a limited number of locations awaiting customer orders, or 'form postponement', where the final manufacturing or assembly is delayed until customer orders are received (van Hoek, 1998). Form postponement is being increasingly added to logistics postponement, resulting in postponed manufacturing activities within the supply chain (van Hoek, 1998). This concept of holding product in a generic form awaiting final assembly or localization is viewed as being a vital element of supply chain agility (Christopher, 2000). Postponement may occur at various points in supply chains, but as distribution centres are frequently the final point of despatch to the customer then these are seen as being a key option (Tompkins, 1997).

Outsourcing: Organisational agility is often viewed as a key component of supply chain agility, as expressed by terms such as the extended enterprise (Christopher, 2000), virtual corporation (Mason-Jones *et al.*, 1999), and virtual

teaming (Bal *et al.*, 1999). Third-party logistics contractors are part of this agile organisational structure and are regarded as being well positioned to coordinate and integrate capabilities to provide a dynamic response to volatile markets (Morash, 2001). In terms of distribution centres, the flexibility offered by the use of third-party logistics contractors is likely to be particularly marked in relation to shared-user facilities, where space and other resources can more easily be diverted from one customer to another in response to variations in demand.

In order to ascertain more precisely how distribution centres would need to be designed and operated to respond to volatile markets, it is necessary to examine what types of volatility may occur. There has been relatively little research in this area, but van Hoek (2001) did classify three areas that agile supply chains would need to master and benefit from, namely:

- *Volume variance*, for example seasonality, product life cycles and random consumer demand
- *Time variance*, such as urgent orders
- *Quantity variance*, for example item level orders instead of case level orders

This classification forms the initial basis for some of the research described in this thesis.

2.4 The design and operation of distribution centres

Literature base:

The history of warehousing goes back thousands of years, for example to the storage of grain when crops were first harvested. The literature also goes back a long way, although modern literature reviews start with Cahn (1948) who examined what he termed as the ‘warehousing problem’ examining the optimal pattern of purchasing, storage, and sales, given a finite warehouse capacity (as per Ashayeri and Gelders, 1985). The latter review charts some of the analytical methods used in papers during the 1960s, 70s and 80s. Many of these are mathematical analyses of specific operations or equipment within a warehouse and are based on restrictive boundary conditions. Although these provide a valuable insight into particular operations, they do not consider the warehouse as a whole or the warehouse operations within the context of the overall supply chain. This view held by Ashayeri and Gelders in 1985 about the restricted nature of warehousing literature is supported by the later literature review of Rouwenhorst *et al.* (2000) who concluded that the majority of papers provided isolated analyses of particular warehouse problems and that there was little synthesis of these models and techniques.

Warehouse design:

The overall design of warehouses is particularly important as the logistics costs associated with warehouses are largely determined during the design phase (Rouwenhorst *et al.*, 2000). In spite of this significance, the design of warehouses is still very subjective. This is demonstrated by the conclusion of Goetschalckx *et al.* (2002, p.1) that:

“a comprehensive and science-based methodology for the overall design of warehousing systems does not appear to exist”

Although there is a wealth of material on the design of particular aspects of warehouses, such as layout, order picking policies and equipment choice, it is the integration of these methods to form an overall methodology that appears to be lacking (Rouwenhorst *et al.*, 2000).

Warehouse design methodologies tend to be structured around a number of sequential steps. Key publications in this area include Apple (1977), Firth *et al.* (1988), Hatton (1990), Mulcahy (1994), Oxley (1994), Govindaraj *et al.* (2000), Rouwenhorst *et al.* (2000), Rowley (2000), Rushton *et al.* (2000), Bodner *et al.* (2002), Hassan (2002), and Waters (2003). These publications list between five and fourteen steps, depending largely on how they group the activities together. A typical set of steps for warehouse design is set out by Rushton *et al.* (2000), as follows:

- Define system requirements and design constraints
- Define and obtain data
- Analyse data
- Establish what unit loads will be used
- Postulate basic operations and methods
- Consider possible equipment types for storage and handling
- Calculate equipment quantities
- Calculate staffing levels
- Prepare possible building and site layouts
- Evaluate the design against system requirements and constraints
- Identify the preferred design

Although these steps are set out in a sequential fashion, the authors acknowledge that this is very much an iterative process, checking back to assess the interactions that occur as the design progresses. During ethnographic research with warehouse designers, Govindaraj *et al.* (2000) found that the designers relied heavily on their own experience, intuition and judgement in order to solve some of the complex decisions with which they are faced.

The typical initial steps of obtaining and analyzing data to form a planning base tend to be centred on ‘the business plan’ for a certain number of years ahead. Flexibility or agility is not a specific step in any of the above papers, although Hassan (2002) makes a few specific suggestions in this regard, such as multiple docks (doors), locating an item in several bays, and the use of cross aisles. Rowley (2000, p.4) does add a final step of “computer simulation of the proposed warehouse with different volumes and the consequences on the rest of the supply chain”. However, this addition of

sensitivity analyses of the preferred design does not really constitute the incorporation of flexibility within the design process itself. The typical design steps thus do not directly address the issue of supply chain agility.

DC operations:

In terms of warehouse operational literature, a review by Gu *et al.* (2007) found that whilst there was a significant amount of literature, this was concentrated in a few detailed areas (e.g. product-location allocations and pick routes). They also found that there is a need for the research to be positioned more in line with the dynamic environment in which warehouses operate. Although distribution centres have been changing in order to be able to respond to volatile markets (Maltz and DeHoratius, 2004), research into agility at the DC operational level has been very limited to date.

DC performance measurement:

This is exemplified by an examination of key performance indicators (KPIs). Warehouse performance metrics have traditionally been focused on ratio-based measures, such as operating costs and labour productivity, together with service measures such as response time and shipping accuracy (Hackman *et al.*, 2001). These types of measures have been classified by Frazelle (2002a), as follows:

- Financial (e.g. cost per item)
- Productivity (e.g. order lines picked per man-hour)
- Utilisation (e.g. percentage utilisation of equipment))
- Quality (e.g. percentage of perfect shipments)
- Cycle time (e.g. putaway cycle time)

The first three classifications are all concerned with ‘cost’, rather than the ‘service’ aspiration of agility. The quality and cycle time classifications are more relevant, but these tend to examine service in a steady state situation. The use of these simple ratio measures has been criticised as being inappropriate by Hackman *et al.* (2001), who state that an approach is needed that considers several dimensions of performance simultaneously. This view is supported by the research of Aminoff *et al.* (2002) who found that performance metrics were greatly affected by factors outside of the control of the warehouse, such as the number of lines per order. Hackman *et al.* (2001) have used Data Envelopment Analysis (DEA) to provide an approach that can examine all of the inputs and outputs of warehouses simultaneously so as to provide a wider efficiency measure. However, this is still a measure of a static-state environment, and does not provide a metric for the degree to which a distribution centre may contribute towards supply chain agility.

DC resources:

Although the warehousing literature does not address supply chain agility directly, it does provide a framework of the elements that need to be taken into account during warehouse design. For example, Hatton (1990) lists:

- Land and building
- Equipment
- Management and staff
- Computer and its software
- Operating methods and procedures

This list of design elements is used later in this thesis to examine how distribution centres can be designed and operated to provide supply chain agility.

2.5 The gap between supply chain agility and distribution centre literature

The last two sections indicate that there is some disconnect between the literature on supply chain agility and that on distribution centres. The supply chain agility publications tend to focus on organisational matters and just give a few indications of the implications for distribution centres, whilst the distribution centre publications tend to focus on specific areas of the operation rather than looking at distribution centres in their supply chain context.

This disconnect appears to be somewhat wider in that it affects supply chain management and warehousing literature in general. For example, Higginson and Bookbinder (2005, p. 67) state that:

“A review of supply chain management books published from the late 1990s onward reveals that many do not discuss, nor even include in the index, material on distribution centres or warehouses”

This view is supported by Du (2003), who found that only 2 out of 32 supply chain strategy publications that he examined mentioned warehousing in passing, and that none of these discussed the implications for warehousing in any detail. Similarly, only 6 out of 36 warehousing publications mentioned supply chain strategy and that none discussed the role of warehouses within the context of supply chain strategy in any detail.

In order to investigate this apparent gap in more detail, it was decided to conduct a database search as part of this research. The selection of the appropriate databases was based on an analysis of those most commonly used for top ranking logistics and supply chain academic journals (NB Those specifically related to transportation were excluded from this list). Within Cranfield School of Management, journals are classified into subject headings and then classified on a scale of 1* to 4* according to their academic standing (4* being the highest ranking). A search of the Library Catalogue at Cranfield University was then undertaken to identify the appropriate databases for the logistics and supply chain journals ranked 2* and above (see Table

2-1). Where two databases are mentioned, the primary database listed is the one holding current papers, whereas the restricted database only holds older papers.

Journal Title	Ranking	Primary Database	Restricted Database
International Journal of Logistics Management	3*	Emerald Insight	Proquest
International Journal of Logistics: Research & Applications	2*	-	Ebsco Host
International Journal of Physical Distribution & Logistics Management	3*	Emerald Insight	Ebsco Host
Journal of Business Logistics	3*	Proquest Ebsco Host	-
Journal of Purchasing and Supply Management	2*	Science Direct	-
Supply Chain Management: An International Journal	3*	Emerald Insight	-
Transportation Research – Part E: Logistics	3*	Science Direct	-

Table 2-1 Electronic databases for top ranking logistics journals

Based on this table, it was decided to use the following four databases for the searches:

- Ebsco Host
- Emerald Insight
- Proquest
- Science Direct

These four databases also cover other journals that regularly publish supply chain papers, including the International Journal of Operations and Production Management, International Journal of Production Economics, International Journal of Production Research (except the last 12 months), and the European Journal of Operational Research.

The following strings were used in the database searches to determine whether there is a disconnect between distribution centre and supply chain agility literature:

‘distribution cent’ OR warehous* (AND NOT ‘data warehous*’)*

AND

agility OR flexibility

(Note: ‘*’ represents any combination of letters)

The searches covered all dates on the databases and examined the titles and abstracts (plus keywords, where available) of the papers. The precise search mechanisms had to be adapted slightly for each database according to the options available on the advanced search engines of each. The search was restricted to scholarly papers where this was possible.

The results of the database searches are shown in Table 2-2 and detailed in Appendix A (after excluding three papers: an own paper, one relating to information warehouses and one on financial affairs). Only three papers were found that mentioned distribution centres / warehouses and agility in their title or abstract. Of these three, two were manufacturing papers: one on agile manufacturing in the aerospace industry (Gunasekaran *et al.*, 2002) and one on industrial robotics (Pires, 2005). The third paper (Hyland *et al.*, 2003) studied the application of continuous improvement practices from the field of product innovation into the distribution function. This investigated organisational learning, which is very important for enabling change to take place on a continuing basis. This can be regarded as an important parallel stream of research to this thesis which is concerned with what change should take place at the operational level of the distribution centre.

Database:	EBSCO	Emerald	Proquest	Science Direct	Total number of different papers
Search string:					
distribution cent* OR warehous* AND agility	0	1	2	1	3
distribution cent* OR warehous* AND flexibility	0	5	21	2	24
Total number of different papers	0	5	21	2	24

Table 2-2 Distribution centre / warehouse and agility / flexibility search results

A further 21 papers (plus the 3 mentioned above) were found when the term flexibility was searched in conjunction with warehouses / distribution centres. From these, the following should be noted as being of some relevance to this thesis:

- Hassan (2002): A framework for designing warehouse layouts, with flexibility being listed as a characteristic of the final design. Some specific suggestions from the paper are mentioned in section 2.4 above.
- Jayaraman (1998): The use of heuristics in distribution network design, including the incorporation of flexibility at the network level.

- Larson and Gammelgaard (2001): A survey indicating that flexibility is one of the performance benefits of buyers, suppliers and logistics service providers working together collaboratively.
- Parry (1992): A single case study of an automated warehouse implementation, incorporating planned flexibility for the future by designing in the possibility of adding an extra pallet crane.
- Pollitt (2006): An example of the use of interim management to provide flexibility in a warehouse.
- Sanders and Ritzman (2004): A case study examining the use of warehouse workforce flexibility (i.e. part-time labour and cross-training) to offset forecast errors.

Whilst some of these provide a useful insight into particular aspects of flexibility, no paper was found that was aimed directly at researching the overall link between supply chain agility / flexibility and distribution centres.

A further search was then undertaken to examine the wider issue of a possible disconnect between supply chain management and warehousing literature. For this, the following terms were used.

'distribution cent' OR 'warehous*'(NOT 'data warehous*')*
AND
'supply chain strateg' OR 'supply chain management'*

The results of the searches are shown in Table 2-3 below and are detailed in Appendix B.

Database:	EBSCO	Emerald	Proquest	Science Direct	Total number of different papers
Search string:					
distribution cent* OR warehous* AND supply chain strateg*	0	1	1	1	3
distribution cent* OR warehous* AND supply chain management	0	24	37	6	55
Total number of different papers	0	25	37	7	57

Table 2-3 Distribution centre and supply chain strategy / management search results

Only three papers were found that mention distribution centres and supply chain strategy. One of these (Green, 2001) discusses emerging trends in the use of ERP (enterprise resource planning) and SCP (supply chain planning) software, whilst another paper (i.e. Wilhelm *et al.*, 2005) presents a mixed integer programming model as a decision support aid for the design of assembly systems under the North American Free Trade Agreement. The third paper (Perry, 1996) is of more relevance in that it uses gap analysis within a single case study to examine the service provided by a distribution centre and then examines whether automation could be used to help fill these gaps. However, none of these papers examine the overall link between supply chain strategy and distribution centres.

The search was then extended to find papers that mention distribution centres and supply chain management. This provided a total of 55 different papers, of which the following may be noted as being relevant to this subject:

- Bourlakis and Bourlakis (2001): Seven case study companies are examined in the Greek food retail sector and this study concluded that warehousing plays a key part in multinational retailers' strategies. It points out that logistics, and in particular warehousing, may not only be an important tool for a firm's expansion plans but may also be a source of competitive advantage.
- Buxey (2006): This examines whether conventional inventory control theory is appropriate for certain case study supply chains and concludes that a more holistic view needs to be taken to include such factors as level transport flows.
- Kiefer and Novack (1999): This paper examines the relationship between firms implementing a supply chain strategy and the warehouse measures that they use. The study found that measures reflecting the entire process were more likely to be used by firms that are in the process of implementing a supply chain strategy.
- Tracey *et al.* (2005): This empirical study found that there was a positive relationship between supply chain management capabilities (which included materials warehouses and finished goods warehouses) and business performance.

However, again no paper was found that examined the overall link between supply chain strategy and distribution centres. With a few exceptions, there appears to be a general disconnect between the bodies of literature in these two areas.

2.6 Manufacturing agility and flexibility literature

Although the literature in the supply chain agility and distribution centre arenas is rather limited on the specific subject of DC agility, there are some useful frameworks available from the substantive body of literature on manufacturing agility and flexibility. As noted earlier, the concept of agility originally stemmed from the manufacturing literature, which covered such areas as flexible manufacturing systems and routing flexibility. This literature on flexibility tends to be more established than that on agility, as noted by Giachetti *et al.* (2003).

The literature covers many dimensions of manufacturing flexibility, such as volume, mix, and modification flexibilities. These have been placed in a hierarchy of flexibility dimensions by Koste and Malhotra (1999), as follows:

- Strategic business unit
- Functional (e.g. manufacturing, research and development, and marketing)
- Plant
- Shop floor
- Individual resource (e.g. machine or material handling)

There are thus different levels at which flexible competences can be designed to offer an agile capability to the market place.

This agile capability is normally required across specific ‘dimensions’. Upton (1994) gives some examples of dimensions, such as the mix of products, the output rate, and the ability to use different input materials. These ‘dimensions’ may be likened in supply chain terms to the different types of agility identified by van Hoek (2001), namely volume, time and quantity, as mentioned earlier.

Upton (1994) also noted three elements of flexibility, which he named as:

- Range (e.g. the volume or number of products to be produced)
- Mobility (e.g. the time or cost of change)
- Uniformity (e.g. constant yield or quality)

These can form the basis for both identifying the nature of the agility required as well as providing a measurement framework for agility. The mobility element also encompasses the definition of agility by Prater *et al.* (2001) which involves firms being able to respond to change within a useful time frame.

It is interesting to note that Upton (1994, p. 89) concludes by stating that the exhortation “Go forth and be flexible” is meaningless, as managers need to identify the precise types of flexibility required. This research takes the same view in that the starting point for how distribution centres should be designed and operated for agility should be the range of agility types that they may need to accommodate in the future.

2.7 The role of automation within agility

Although agility stems from such concepts as flexible manufacturing systems (Christopher, 2000), automation within warehousing is often viewed as being a potential constraint on flexibility (e.g. Matthews, 2001 and Allen, 2003). This is demonstrated for example by Kamarainen and Punakivi (2002) who examined contributory factors to business failures in the e-grocery market. They found examples of overinvestment in DC automation and problems caused by the inflexible capacity of automated systems in responding to demand variations.

There is little mention of warehouse automation within supply chain agility literature, although Harrison and van Hoek (2002) mention that automated sortation systems may be used for cross-docking within stockless distribution centres. Similarly, Marvick and White (1998) mention the potential role of conveyors and sortation equipment within postponement, namely that such systems could be used to direct goods to various value-adding activities without being placed into storage.

The reasons for companies investing in DC automation were examined by a US survey a number of years ago by Dadzie and Johnston (1991). They found that the main motivations for purchasing an automated system were to reduce the amount of handling, improve consistency of service, increase accuracy and improve the speed of service. The main criteria used in the decision to automate were labour cost reduction, the ability to increase output rate, and service availability. Offsetting these potential benefits, Hackman *et al.* (2001) found some inefficiencies in highly automated warehouses, which they attributed to a possible lack of system maintenance, inappropriate selection of system types and the difficulty of reconfiguring automated systems to meet changing business requirements. They also point out that automated systems may experience 'burn-in' difficulties immediately after implementation which may impact temporarily on their efficiency. This can have a significant impact on responsiveness during this initial period, as evidenced by some instances of DC automation implementations leading to profit warnings in blue-chip companies (Emmett, 2005).

The role of automation is examined as part of this research in the context of the above.

2.8 Literature review summary

The literature on supply chain agility is still in the theory development stage and has been largely concentrated on the organisational and information aspects of supply chains. There are some implications for distribution centre design but these have not been the focus of research to date. Literature on warehousing and distribution centres goes back much further but has tended to concentrate on the modelling of particular operations within a warehouse under specified conditions (which by their nature are simplifications of the real world). The warehousing literature has generally not examined warehouse design or operations within the context of the overall supply chain, and has not extended to such concepts as supply chain agility. There is thus a substantial disconnect between the two bodies of literature.

However, manufacturing agility / flexibility literature is in a position to provide a link between the two. On the one hand, it is acknowledged that supply chain agility literature originally emanated from this base and, on the other hand, the manufacturing literature has extended to the operational level, which is relevant to warehousing. This situation may be shown by the Venn diagram in Figure 2-1, with there being hardly any overlap between supply chain agility and DC design / operations literature, but manufacturing agility / flexibility literature overlapping with both.

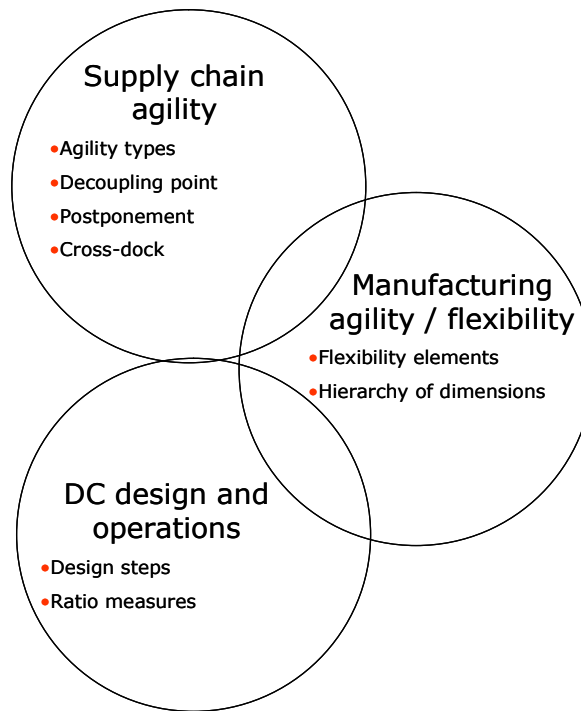


Figure 2-1 Venn diagram of key areas of literature

3 RESEARCH QUESTIONS

The review of the literature indicates that there is a substantial gap in terms of the role of distribution centres within agile supply chains. The literature on supply chain agility has so far focused on organisational, network and information aspects and has not yet been extended into such operational areas as distribution centres. The implications for distribution centres from the literature are somewhat ambivalent in that, on the one hand, inventory is regarded as being required at decoupling points whilst, on the other hand, it is regarded as being a key source of non-responsiveness. The precise role of distribution centres in agile supply chains therefore needs to be explored.

The warehouse design literature provides ‘good practice’ approaches for the design of distribution centres to meet specified future business plans but does not explain how flexibility should be incorporated into these designs. Warehouse operational literature was found to be similarly lacking in that it does not tend to examine the dynamic environment in which distribution centres operate.

The literature on DC performance measurement has been developing away from simple ratio based measures to more sophisticated techniques such as Data Envelopment Analysis. However, even with this development, the measurement of DC agility has not been addressed.

Some of the bodies of literature outside supply chain management appear to offer approaches and frameworks that may be relevant to the exploration of DC agility. This particularly applies to the manufacturing agility literature, which has examined agility at the operational level, albeit within production facilities rather than distribution centres. These approaches are used, where appropriate, within the research described in this thesis.

The above gaps in the literature lead to the following key research questions that have been adopted:

- Is there a role for distribution centres in agile supply chains, and, if so, what is that role, or roles?
- How can distribution centres be designed and operated to support agile supply chains? In particular, what is the role of automation?
- How can distribution centre agility be measured?

4 RESEARCH METHODOLOGY

4.1 Overall approach

As there is a substantive gap in the literature concerning the role, design and operation of distribution centres in agile supply chains, this research is, by its nature, largely exploratory.

Figure 4-1 demonstrates the overall approach used in the context of some ontological and epistemological positions, and places this research broadly in the realm of relativism in both domains. The lower shaded area shows the first stage of the research, which tended somewhat towards a positivist approach in quantifying the current situation, whereas the upper shaded area shows the second stage, which tended more towards an interpretive approach in order to gain a fuller understanding of the reasons underlying the findings. This mix of approaches fits well with my own position in accepting that there is value in the wide spectrum of approaches shown and that each should be used in terms of their suitability to the nature of the research being undertaken.

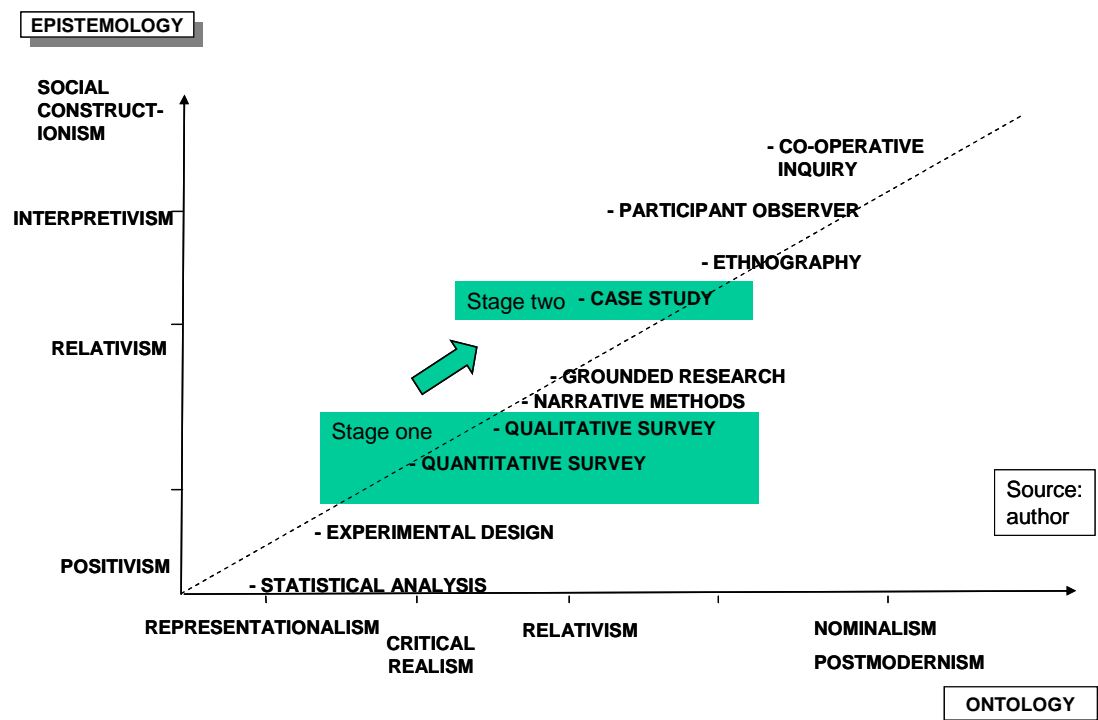


Figure 4-1 Overall approach

In order to address the question of the role of distribution centres in agile supply chains, it was decided that the first step would be to examine the current situation and, in particular, to determine to what extent the distribution centre characteristics implied by the supply chain agility literature were actually in use. This part of the research was suited to a quantitative approach across a large number of distribution centres and

therefore a survey technique was adopted. This choice can be supported by the matrix drawn by Easterby-Smith *et al.* (2002, p. 57), which places the survey approach in the quadrant where a positivist view is sought and where the researcher wishes to remain detached from the research. Similarly, Yin (2003) considers that surveys are appropriate for answering ‘how many?’ questions within a contemporary setting.

Having established the current situation, the main part of the research, as identified by the research questions, has been to explore in more detail the role of distribution centres within agile supply chains and how these DCs can be designed, operated and measured. A more qualitative approach was adopted for this, as supported for example by Cavana *et al.* (2001, p. 96), who advise that qualitative research strategies “are ideally suited to investigating the research topic more deeply”. The method used through this main part of the research was a multiple case study approach. Easterby-Smith *et al.* (2002, p.57) place the “case method (Yin)” in the quadrant for a social constructionist approach where the researcher is detached from the subject under investigation. Yin (2003) supports this choice in that he views the case study approach as being suited to answering ‘how’ type questions in a contemporary setting. In fact, case study research has become a fairly established method in the logistics field for various purposes, including exploratory research and the extension of current understanding and theory (Dinwoodie, 2007).

Yin (2003, p.13-14) states that a case study “investigates a contemporary phenomenon within its real-life context”, “copes with the technically distinctive situation in which there will be many more variables than data points”, and “relies on multiple sources of evidence, with data needing to converge in a triangulating fashion”. These descriptions match well the research area being considered.

The overall approach is mainly inductive in nature with phenomena first being observed, both from the survey and from the case studies, and then relationships and frameworks being formulated from these. However, some pre-existing frameworks have been taken from the existing literature and these have been tested and consequently extended during the case study research. This constitutes a deductive aspect of the research. Using a mix of inductive and deductive stages, and employing both quantitative and qualitative techniques, is regarded as a suitable means of providing valuable insights within the field of logistics research (Mangan *et al.*, 2004). The study adopted a pragmatic ontology (Saunders *et al.*, 2007) in which the study methodology was driven by the research questions.

The unit of analysis for most sections of this research is the distribution centre. This provides a clear unit that can be delineated and can be recognised easily by practitioners. This unit also has the advantage of encompassing all the different types of operation that may occur within it, for example storage, cross-docking and postponement, as described in section 1.2. However, the DC is always considered within the context of the overall supply chain of which it is a part and some aspects of the research thus relate to the supply chain. This is particularly true where the roles of DCs are examined in section 4.3 below, and in this case the unit of analysis is the supply chain.

4.2 Exploration of current situation

In order to explore the current situation, a survey was conducted, based on the supply chain agility literature. The survey questions examined the themes that had been identified as being the implications for distribution centres of supply chain agility (i.e. low inventory holdings, short customer order lead times, cross-docking, postponement, and outsourcing). The survey questions were quantitative in nature in order to ascertain the extent of these themes being adopted in practice.

The survey was based on a comprehensive database of warehouses that had been set up by King Sturge (international property consultants) to monitor the UK warehouse property market. Three factors should be noted about the scope of the database:

- Large warehouses (i.e. over 100,000 square feet in area): These therefore represent significant supply chain investments, but do not include networks of (or individual) smaller warehouses. Distribution centres were not specifically identified in the database, but, in fact, all the replies were from distribution centres, except for one warehouse that sequenced components to an automotive assembly line.
- Recent constructions (i.e. 1995 to 2001): They are therefore relevant to recent supply chain trends.
- United Kingdom: The results are obviously relevant to the UK, but may not be representative of other countries.

Bearing these factors in mind, this was considered a useful starting point for this exploration. A survey form was piloted with a warehouse consultancy firm and then the refined survey (e.g. including additional added value activities) was posted to warehouse managers identified from the database. Forty-five usable responses were received, representing an 18% response rate as a percentage of the survey forms sent out and 16% of the total square footage area of the warehouses constructed during the specified period. A copy of the full survey form, which also included questions on other aspects of warehousing, is shown in Appendix C.

4.3 The role of distribution centres

Having examined the current situation, the next step in the research was to explore the precise roles in which companies were using distribution centres. For this part of the research, it was decided that the appropriate unit of analysis would be the supply chain rather than the individual distribution centre. In this way, the different roles of various warehouse facilities along the supply chain could be explored. A case study approach was adopted so that a rich understanding of the supply chains could be gained.

The participating companies comprised two industrial manufacturers (from the agricultural and automotive sectors), two fast-moving consumer goods (FMCG) manufacturers (one food and one non-food) and two retailers (one department store chain and one fashion chain). The research was introduced to the first five companies in a group meeting and the research tools (as described below) were discussed and

refined at that meeting. The fashion chain was included within the research about two weeks later in order to provide a reasonable cross-section across industrial sectors.

The key method used was that of supply chain pipeline mapping (as per Scott and Westbrook, 1991), which is well suited to analyzing long and complex supply chains. As noted earlier, one of the key roles of distribution centres is the holding of inventory and thus it was considered important to ascertain the role of inventory in these supply chains. The number of days inventory holding at each point was thus recorded, as well as the function of any other warehousing activity along the supply chain. The participants were asked to complete a pipeline template for each supply chain, and this was supplemented by a questionnaire. The latter not only included questions about the supply pipeline (e.g. inventory holdings and lead times) but also examined the participants' views with regard to the sources of risk, the extent of risk and any avoidance actions taken (as per Svensson, 2004). These views were considered important to explore the perceptions of inventory as a source of risk or as a means of risk mitigation (as per Chopra and Sodhi, 2004). This aspect was measured on 5-point Likert scales, as being a reasonable means to ascertain perceptions. A copy of the questionnaire is attached at Appendix D.

The research was conducted with the key company in each supply chain, but did not extend outside the operations of those companies. In line with the focus of this research, the supply chains were examined from the point of manufacture to the point of use, or to the shops in the case of retail goods. The research thus covered the outward physical distribution segment.

Thirteen supply chains were examined (about two from each of the seven companies). The participants were asked to select 'typical' international supply chains for their goods. It should be noted that 'international' supply chains were stipulated, as this was the theme of the conference for which this paper was targeted (the Logistics Research Network Conference, 2006). This was considered highly relevant owing to the rapid growth in international trade, although it should be noted that the findings may not be generalisable to domestic supply chains.

Of the thirteen supply chains examined, six involved sea freight (by container) and seven involved international road transport movements (NB no air or rail routes were selected by the participants). The sea routes covered Asia, Europe and the USA, whilst the road routes were across Europe.

4.4 The design, operation and measurement of distribution centre agility

Following the exploration of the roles of distribution centres within supply chains, the next stage of the research was to explore their design, operation and measurement. For this, a case study approach was also adopted, but with the unit of analysis being at the individual DC level. As there was very little literature on this aspect within warehousing publications, it was decided to use a combination of frameworks from supply chain agility and manufacturing agility literature.

This research was undertaken from two different viewpoints:

- The DC designer
- The DC operator

Two separate series of case studies were used to explore these viewpoints. Semi-structured interviews were conducted with six warehouse design companies (covering 11 DC designs) and nine company business units (covering manufacturers, wholesalers, retailers and direct sellers).

Rather than exploring 'agility' as a general term, it was decided to adopt the approach in the manufacturing agility literature (e.g. Upton, 1994) to identify the different dimensions of agility that are required. To do this in supply chain terms, the different types of supply chain agility set out by van Hoek (2001) were used:

- Volume variance
- Time variance
- Quantity variance

The participants were asked to ascertain the extent to which each of these was important for the design or operation of the distribution centre in question. This corresponds to the 'range' element of flexibility identified by Upton (1994). The responses were measured on a 5-point Likert scale. Having ascertained the important dimensions of agility for each distribution centre, the participants were then questioned as to the way in which the DC was designed or operated to meet these requirements. In the case of the DC operators, the participants were brought together at a workshop at the end of the research to refine their responses in the light of additional agility types that had been identified and to discuss the practical implications of the findings.

For the operators a wide view was taken as to how the required agility was provided by the whole 'system' of which the distribution centre was considered to be a part. The hierarchy of flexibilities approach of Koste and Malhotra (1999) was therefore adopted as a framework for this.

For the designers a more detailed investigation at the DC level was adopted. The designers were asked how much the provision of this agility cost in terms of capital and operating costs, how quickly the agility could be provided, and whether this could be achieved whilst maintaining the same service level to the end customer. The latter two questions are in line with the 'mobility' and 'uniformity' elements of flexibility identified by Upton (1994), and are relevant to design, operation and measurement. All of these aspects were measured on 5-point Likert scales.

The semi-structured interviews and Likert scales used with DC designers are set out in Appendix E and those for DC operators are shown in Appendix F.

4.5 The role of automation

The specific role of automation was explored by means of a questionnaire approach. First of all, semi-structured interviews were conducted with eight companies involved in automation implementation projects, drawn from consultancy firms, materials handling system suppliers and end user companies. A questionnaire was developed from these interviews and sent out to members of the Warehouse and Materials Handling Forum of The Chartered Institute of Logistics and Transport (UK). Thirty two members of the Forum had previously indicated that they would be willing to support such a survey and out of these 19 usable responses were received, covering 27 warehouse automation projects. Although this is a small sample, it was estimated that this may broadly cover 10% of the automation projects in the UK during the period covered by the sample.

The questionnaire (see Appendix G) requested both quantitative and qualitative information in order to gain an insight into the projects. It was divided into the following parts:

- General information about the company and project
- Decision factors
- Pre-project stage
- Implementation stage
- Post-project stage

The responding companies included manufacturers, wholesalers, retailers, third party logistics companies and consultancies. The nature of the automated equipment installed during these projects covered material movement (e.g. conveyors and automated guided vehicles), sortation, order picking, and unloading / loading systems. The results were analysed by frequency of occurrences and by the commonality of qualitative comments made by the respondents to provide an initial insight into the reasons for automation, how companies automate, the project timescales, and the impact of the projects on the ongoing operations.

4.6 Summary of methodology

Following an initial survey to explore the current situation, a qualitative case study method has been adopted in order to gain an understanding of the role, design and operation of distribution centres in agile supply chains. These case studies have been conducted with both designers and operators of DCs, and, in the case of the latter, have been undertaken at a combination of supply chain and DC levels. Finally, a survey method has been used to explore the specific role of automation. This integrative approach is in line with the nature of supply chain management which is well suited to the use of multidisciplinary methodologies (New and Payne, 1995).

5 RESULTS AND EXPLORATORY FRAMEWORKS

This section summarises the key results from the research, describes the interpretation of these results and sets out a series of exploratory frameworks that have been developed. The detailed results can be found in the published papers, which are referenced in brackets in the sub-titles.

5.1 The current situation (Paper 1)

The current situation was surveyed to identify the extent to which the distribution centre concepts, commonly associated with agility, are actually in use. The concepts mentioned in the literature were set out in Chapter 2 and are now compared with the survey results below.

Inventory holdings:

The property database used for the survey indicates that there has been a rising trend in the construction of large (i.e. over 100,000 square feet) warehouses, with new builds being greater in each of the four years from 1999 to 2002 than in the previous four years from 1995 to 1998. Whilst this does not necessarily reflect the trend for warehousing in total (e.g. larger warehouses may be replacing smaller warehouses), it does demonstrate an increasing investment in large warehouses in modern supply chains.

The average inventory holding from the survey was 7.5 weeks. Although there are some 'fast throughput' warehouses (16% reported 2 weeks or less of inventory), the indication is that the inventory holding at these warehouses is significant. This finding may be in line with these large warehouses acting as decoupling points in supply chains.

Customer lead times:

Most warehouses in the survey offered short customer lead times, with 73% offering a same day and / or a next day service (from receipt of customer order to despatch). There was limited evidence of customer service segmentation, with about one third of warehouses offering a variety of lead times.

Cross docking:

In spite of the considerable interest in cross-docking, the results show that 74% of the warehouses surveyed cross-dock 5% or less of their total throughput. Thus, whilst short customer lead times are being offered to customers, the goods are being supplied largely from the warehouses' own inventory rather than being cross-docked through the supply chain. Of course, the goods may be cross-docked later through smaller warehouses further down the chain.

Postponement:

It was found that 71% of warehouses in the survey undertake some form of value-added services, with labeling, pricing and tagging being the most common category (represented in 56% of warehouses). However, it appears that these activities are relatively minor in nature as only 5% of floor area is allocated to value-added

activities. Presumably, most are performed as part of the normal pick and pack operations of the warehouse. On the other hand, 52% of the floor area is allocated to storage, which is what would be expected in a typical inventory holding warehouse.

Outsourcing:

Although 64% of the warehouses are operated by third-party logistics contractors, most of these are dedicated facilities (i.e. used only for the logistics of one client). Shared user facilities represent only 11% of the total, and therefore the flexibility that may be possible by sharing resources between clients is rather limited.

The results of the survey indicate that most of the large warehouses taken up in the eight-year period under investigation are used as inventory holding warehouses, with rather limited postponement, cross-docking, and shared-user outsourcing taking place. These warehouses do provide short order lead times to their clients, but, in general, from their own inventory holdings. If it is accepted that markets are becoming increasingly volatile and that supply chains are required to react in an agile way, then either this is happening only to a rather limited extent within distribution centres or further investigation is required to ascertain the nature of this response at the DC level.

5.2 The role of distribution centres (Paper 2)

The survey of the current situation indicated that large warehouses are being constructed in order to act as inventory holding points. If so, this may fit with the concept of decoupling points, whereby inventory is held to decouple lean supply activities upstream from an agile response to the market place downstream. The finding in the survey that most of these warehouses were providing short lead times to their customers would also support this.

Out of the 13 international supply chains examined within this case study part of the research, significant inventory holding points were found in 11 of the supply chains, as shown in Figure 5-1. The two supply chains that contained no buffer stock were for the initial 'push' of fashion lines directly to stores. These are circled in Figure 5-1. In general, higher inventory holdings were found where lead times from suppliers were greatest, as would be expected from conventional inventory control theory. The two main exceptions to this pattern (shown in diamonds in Figure 5-1 below) were in situations where there were two main inventory holding points – one held by the supplier and one by the customer. This highlights the importance of the transmission of information through the supply chain so that only one inventory holding point is necessary. In the case of single inventory holding points, these all supplied customers within short order lead times and were thus consistent with the concept of decoupling points.

Cross docking points were noted both upstream and downstream of these decoupling points (e.g. for container consolidation, sortation, or transshipment to delivery vehicles). Some distribution centres conducted additional activities, such as packing, goods preparation, and sequencing. One port DC was noted that deconsolidated containers, palletised the goods and then held them for a few days until they were called off by the main inventory holding DC.

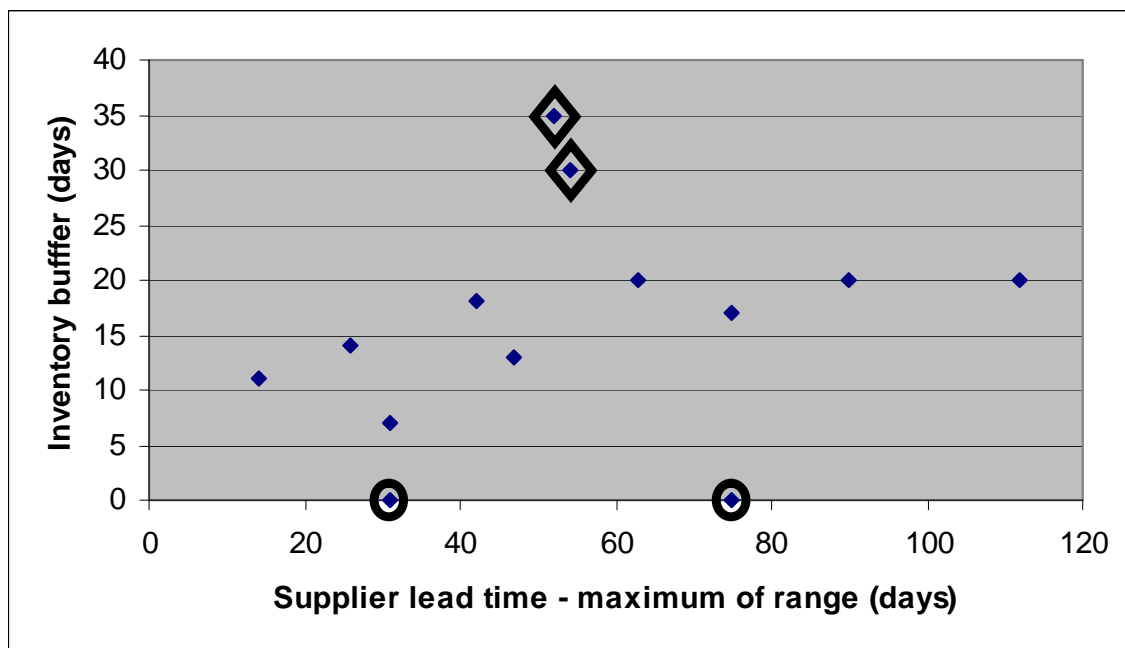


Figure 5-1 Relationship between inventory holdings and supplier lead times

Overall, the supplier lead times were found to be 14 times greater than the customer lead times offered to customers. This finding indicates the extent of the challenge of creating international supply chains that are responsive to customers whilst avoiding the disadvantages associated with holding inventory. For example, one supply chain from China to UK involved a supplier lead time of between 28 and 42 days and yet served customers on a next day basis out of the UK distribution centre. It is difficult to see how such a lead time gap could be bridged by inventory reduction strategies (such as flexible manufacturing systems, time compression, supply chain visibility, inventory centralisation, and reducing minimum order quantities).

A general conclusion from the research is that inventory is required when supplier lead time is greater than customer lead time and when the demand for lines is continuous (i.e. replenishment lines rather than fashion lines).

In addition, the research examined the nature of supply chain risk perceived in each supply chain, together with the risk mitigation strategies adopted. The main risks identified were from forecast inaccuracies and transport delays. Other risks mentioned were failures by the third party logistics (3PL) contractor, quality problems and regulatory delays - the latter being noted for a supply chain to the USA. The use of safety stock was a key risk mitigation strategy adopted by the case study companies, together with closer collaboration (with customers, hauliers, 3PL contractors, and regulatory authorities). Other significant risk mitigation strategies were the use of airfreight to expedite goods and the multi-sourcing of goods.

From the literature and the case study results, an exploratory framework is proposed linking together the various factors that appear to impact on inventory, and hence warehousing, strategies (see Figure 5-2). This framework encompasses the following steps:

- establish the appropriate business model using a demand chain management approach i.e. aligning the organisation's marketing and supply chain strategies. An example of this is Zara who have developed a business model of rapidly introducing a continuous flow of new product lines and thus avoiding the need to hold inventories of finished goods except on display at the shops (Ferdows *et al.*, 2002);
- consider the range of inventory reduction strategies (noted above) and evaluate those that may be applicable;
- identify the potential supply chain risks and their potential impact on the business, and then develop appropriate supply chain risk strategies;
- calculate any supply chain trade-offs (e.g. full container load transport and manufacturing batch runs) by means of total cost analysis, and decide on the appropriate inventory holding policy, taking the identified supply chain risks into account;
- calculate the optimum inventory levels using well established inventory control techniques;
- develop the appropriate warehousing policy, for example, by identifying the necessary decoupling point, together with any cross-docking points upstream or downstream of this.

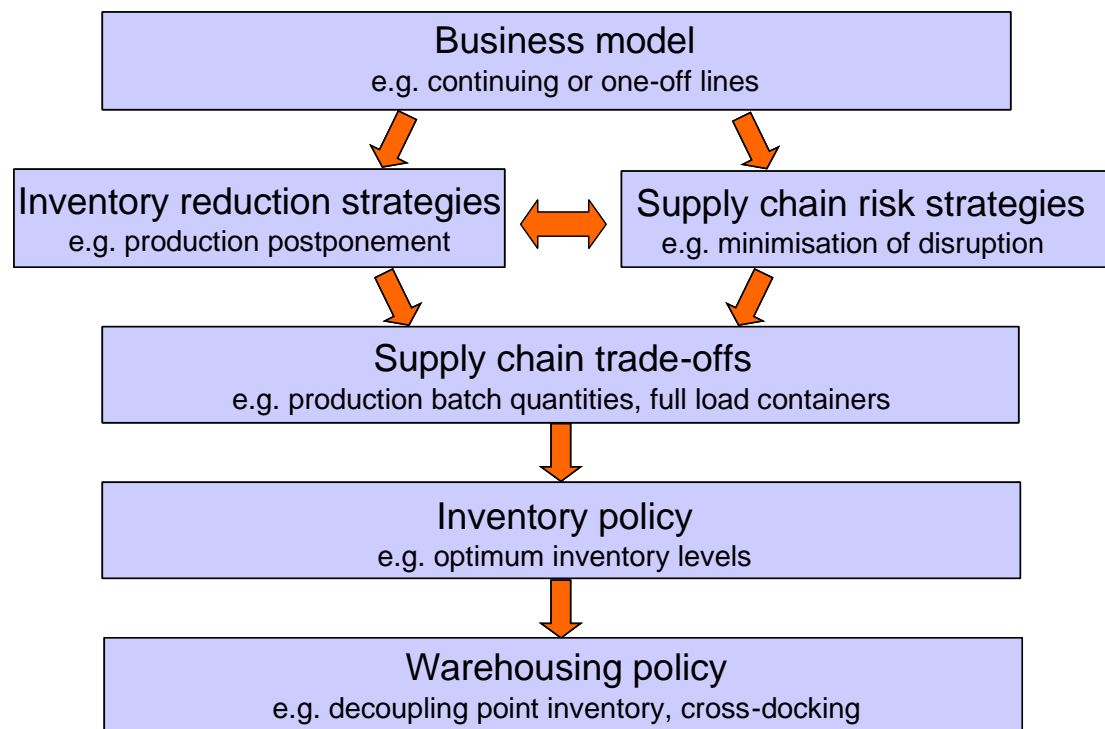


Figure 5-2 Framework to determine appropriate roles of inventory and distribution centres

This framework provides a starting point to determine the ‘correct’ level of inventory for a particular situation, rather than regarding inventory as ‘good’ or ‘bad’ (e.g. the view mentioned earlier by Etienne, 2005, that inventory destroys supply chain responsiveness), whilst taking into account both the latest thinking on inventory and the optimisation approach of conventional inventory control theory. The framework thus builds on the concern of Buxey, 2006 (as mentioned in section 2.5) who found that conventional inventory control theory does not take into account wider supply chain factors such as the benefits of level transport flows. The framework outlined above provides a much wider basis on which to address this issue, but still requires further development. For example, whilst certain aspects can be determined by calculation (e.g. supply chain trade-offs), there are not yet fully accepted methods to calculate other aspects (e.g. supply chain risk).

The roles of warehouses can be further explored by placing the results in the context of the taxonomy of supply chain strategies described by Christopher *et al.* (2006), which is based on the nature of demand (predictable or unpredictable) and the nature of supply (short or long lead-times). Based on conventional inventory control theory, one would expect the necessary inventory holdings to gradually increase as demand becomes more unpredictable and lead times longer (Waters, 2002), as shown in Figure 5-3.

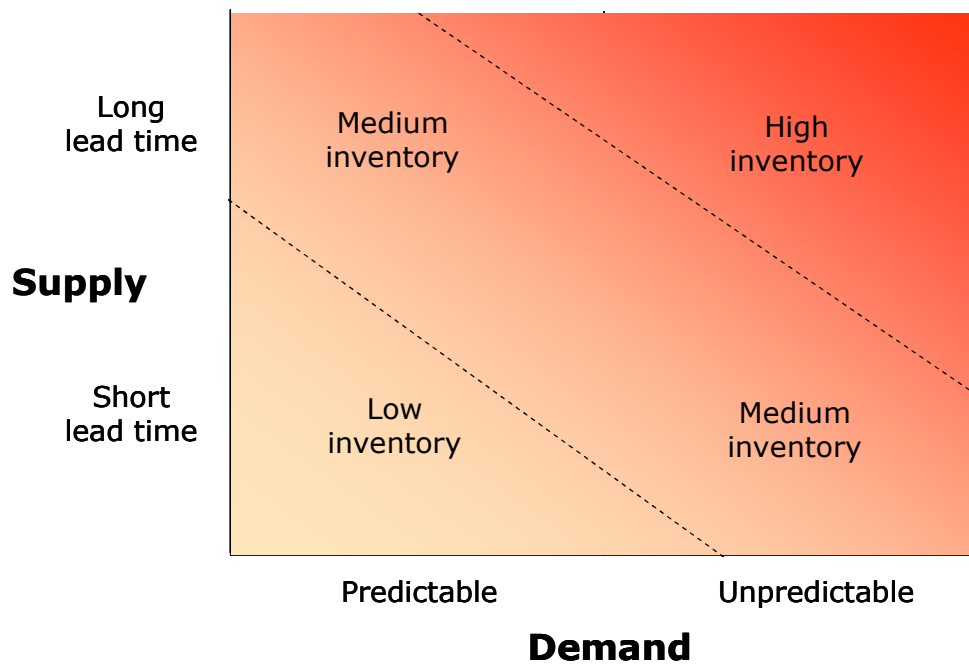


Figure 5-3 Relationship between the nature of demand, nature of supply and inventory levels

The requirement for the application of alternative inventory reduction strategies is thus required most in the top right quadrant of Figure 5-3, and the taxonomy put forward by Christopher *et al.* (2006) suggests a ‘leagile’ approach using postponement (with the example being given of components being held for the final assembly of Hewlett-Packard printers). If this approach is possible, this would suggest a decoupling point holding inventory of components, possibly for final assembly at the warehouse itself. However, if production postponement is not possible or cost effective, then other inventory reduction strategies would need to be considered or substantial finished goods inventories may be needed at a finished goods decoupling point. From the case studies examined, the latter appeared to be a not uncommon situation.

The business model for ‘fashion’ or ‘one-off’ lines is most likely to occur in the short supply lead-time and unpredictable demand quadrant, and an agile strategy (such as that used by Zara) is proposed by Christopher *et al.* (2006) in these circumstances. Within such a strategy, a decoupling point is not needed (except for materials if these have a longer lead time) and therefore a cross-docking distribution centre(s) would be appropriate. Thus, if suitable conditions occur where an agile strategy can be adopted then inventory can be substantially reduced or possibly largely eliminated from the supply chain.

For the two ‘predictable demand’ quadrants, then lean strategies are proposed by Christopher *et al.* (2006) within their taxonomy. With short lead times, a continuous replenishment policy can be adopted with goods being cross-docked through the supply chain from a small finished goods decoupling point (as in the example given for Procter & Gamble / Wal-Mart). With longer lead-times, a ‘plan and execute’ lean strategy is proposed. For this, the finished goods decoupling point may be greater, but this would depend on the precise nature of the demand. The various warehouse

roles can therefore be superimposed on the Christopher *et al.* (2006) taxonomy as shown in Figure 5-4.

Supply	Long lead time	Lean: Finished goods decoupling point	Leagile: Component decoupling point
	Short lead time	Lean: Cross-dock from small finished goods decoupling point	Agile: Cross-dock fashion lines
		Predictable	Unpredictable
Demand			

Figure 5-4 Taxonomy of supply chain strategies and associated warehouse roles (developed from Christopher *et al.*, 2006)

The above four quadrants are in fact a continuum, as demand is rarely, if ever, perfectly predictable. Thus, if supply lead times are greater than demand lead times and if the products are to be replenished (i.e. they are continuing lines, rather than fashion lines), then inventory will need to be held at a point that decouples demand from supply. Goods may be cross-docked to or from these inventory holding points.

5.3 The design, operation and measurement of distribution centre agility (Papers 3 and 4)

The interviews with DC designers and operators confirmed the three agility types of volume, time and quantity identified by van Hoek (2001) and refined the volume category to show a number of sub-classifications. In particular, the distribution centre may need to respond to variances with regard to either the overall volume of goods or to volumes at the individual stock-keeping unit (SKU) level. In addition to normal demand variance, specific issues with regard to overall volumes were the accommodation of unexpected growth (and contraction) patterns and the handling of unexpected seasonal patterns (e.g. higher than normal Christmas demand and over a shorter period). Agility responses required in relation to individual SKU demand variations included the ability to handle promotional effects and high product churns (i.e. the rapid replacement of existing product lines by newer lines).

In addition to the three categories identified by van Hoek (2001), two further agility types were identified that warranted their own classifications, namely presentation (i.e. variations in how goods may need to be presented to customers, such as different pallet heights) and information (i.e. variations in the nature of information provided to

customers, such as different data fields to be sent electronically or different data sets to be printed onto labels).

As well as the agility required to respond to different market demands, the interviews identified that distribution centres need to be agile to respond to variations in the inbound supply chain (e.g. late arrival of goods, or the need for repalletisation on arrival) as well as in the reverse supply chain (e.g. variations to the condition of returned goods).

The following classification, and sub-classification, of agility types for outbound distribution was identified during the research, as shown in Table 5-1. Similar classifications would apply to inbound and returned goods.

Classification	Sub-classification
Volume	Overall volume <ul style="list-style-type: none"> • Demand variance • Growth • Seasonality SKU volume <ul style="list-style-type: none"> • Demand variance • Life cycles • Promotions
Time	Order cycle (e.g. rush orders)
Unit quantity	Items vs. cases vs. pallets
Presentation	Preparation of goods for despatch (e.g. specific pallet heights)
Information	Electronic (e.g. EDI) Physical (e.g. labels)

Table 5-1 Agility types

Thus, the requirement for a distribution centre to be agile needs to be defined in accordance with these different categories. For example, a distribution centre may be agile in terms of being able to handle a very rapid turnover in product lines as life cycles shorten but may not be able to respond to a sudden surge in overall growth.

It was found that users (e.g. manufacturers and retailers) respond to particular agility requirements at a combination of levels in the supply chain. For example, in order to accommodate rapid growth, the case study companies advised that they were able to do this to only a limited extent at the DC level (e.g. by incorporating extra docks into the building design, by reconfiguring the racking and by using additional shifts). The main responses were at the distribution network level, particularly by procuring more

warehouse space (e.g. by building more own warehouses, renting warehouses, or using 3PL companies who have warehouses readily available). Another response at this level was to change the role of the distribution centre by pushing the decoupling point upstream. There were also responses to accommodate growth at the level of internal integration (e.g. smaller manufacturing runs leading to lower inventory levels, and the use of cross functional planning teams).

In order to accommodate unforeseen seasonal peaks (and, in fact, foreseen peaks as well), most of the case study companies responded primarily at the DC level, chiefly through extra staffing (e.g. use of temporary staff, extra shifts, and overtime / weekend working). There were also examples of responses at the distribution network level (e.g. by arranging for direct deliveries from supply points to customers at peak), at the level of internal integration (e.g. cross functional pre-planning), and at the external integration level (e.g. by sequencing inbound goods more frequently from suppliers).

These different levels of responses can be charted in a similar way as Koste and Malhotra (1999) drew for manufacturing flexibility, but using the levels relevant for distribution as found in the case studies. These four levels are shown in Figure 5-5.

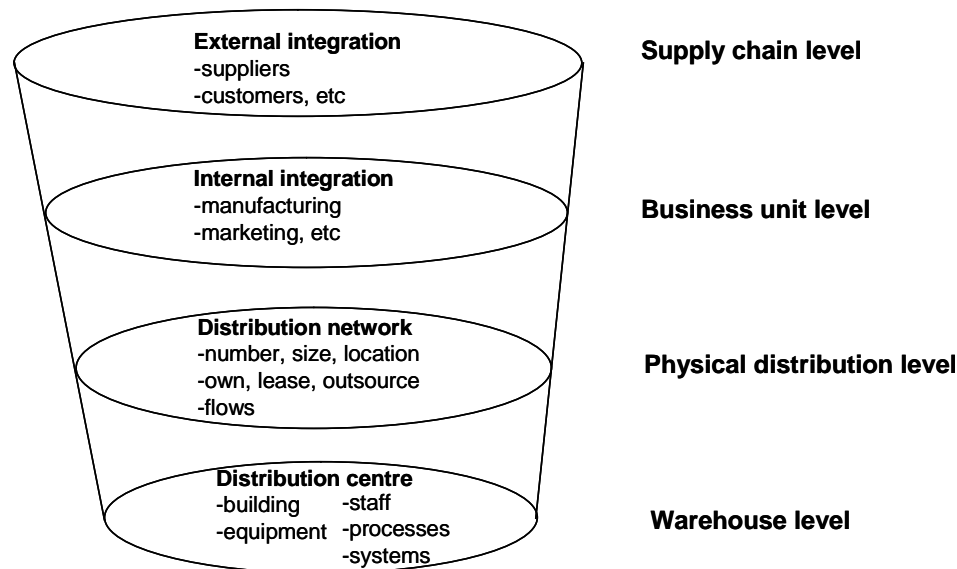


Figure 5-5 Hierarchical framework of distribution responses to agile requirements

It was found in the case studies that different types of agility tended to result in responses at different levels (e.g. growth at the distribution network level and seasonality at the DC level), although most involved a combination of levels. In fact, it was observed that the companies that appeared to cope well with agile requirements used a combination of levels and this view was supported by DC operators in the workshop discussion. However, this hypothesis would require further research to validate.

At the DC level, the interviews with designers provided an insight into the different ways in which distribution centres are designed to meet agile requirements. Responses at this level could be categorised into:

- land / building (e.g. purchase of extra land, and design of the building, for further growth)
- equipment (e.g. the ability to add extra cranes in automated storage and retrieval systems)
- staffing (e.g. the use of annualised hours)
- processes / systems (e.g. the ability to identify when to switch between different picking concepts and the technology to support this)

Each of these in turn could be further categorised into three main methods of providing flexibility, namely:

- extra capacity
- additional resources when needed
- flexible resources

Examples of each of these dimensions are shown in Table 5-2 below.

	Extra capacity	Additional resources when needed	Flexible resources
Land / buildings	Available height for future mezzanine floor	Using extra space when needed in a shared user DC	Free standing mezzanine, rather than a shelf supported mezzanine
Equipment	Conveyor capacity	Hire-in additional fork lift trucks during peak period	‘Combi’ narrow aisle trucks that can be used for picking or pallet putaway / retrieval
Staffing	Staffing at above average throughput level	Agency staff	Multi-skilling
Processes / systems	Availability of multiple processes within the Warehouse Management System (WMS)	Use of software on demand	Processes in place to support pallet, case and item level picking

Table 5-2 Examples of flexible responses at the distribution centre level

These different responses have varying implications in terms of costs, timeframes and service levels, and these were explored during the case study interviews with DC designers. For example, in terms of costs, the provision of extra capacity for land,

buildings, equipment or systems was regarded as incurring 'slightly' (i.e. 0 to 10%) to 'moderately' (i.e. 10-25%) higher capital costs, whilst the provision of extra capacity for staffing was reflected in 'slightly' higher operating costs.

In terms of timeframes, the implications varied from the provision of extra land for future expansion which may take many months to bring into use to the provision of extra conveyor capacity which would be available immediately. Even with using additional resources when needed (e.g. temporary staff) or flexible resources (e.g. staff on annualised hours), it was recognised that there was often some delay in making these resources available for operation.

With regard to the uniformity of service levels, the one detrimental area that was recorded in the case studies was the use of additional staff (e.g. agency staff) to handle peak periods of throughput. It was regarded that this results in a 'slight worsening' of service levels.

It was noted in Chapter 1 that many definitions of agility reflect the 'aspirational' nature of the concept and this is probably best reflected in the use of flexible resources. This category of response provided a way of handling variance with less than 'slightly' increased costs (i.e. less than +10%), in a very 'short' timeframe (i.e. less than 3 weeks), and with no deterioration in service levels. The one exception to this was the increased capital cost needed for flexible systems solutions. However, it should be noted that flexible resources are most suitable for changes to the mix of requirements, rather than to overall increases in throughput. For the latter, excess capacity needs to be provided or additional resources brought in as required – the former incurring higher capital costs and the latter often involving some time delay.

The results of these case studies generally support the propositions put forward by Suarez *et al.* (1996, p. 225) in their paper on manufacturing flexibility:

- "Different types of flexibility exist and are important to firms in different competitive situations"
- "There are different ways of achieving each type of flexibility" (This research has also shown that some ways are common across different types of flexibility)
- "Different approaches to flexibility may have different costs and tradeoffs"

Power *et al.* (2001) recognise that a range of responses are required to provide supply chain agility. This research at the DC level has supported this premise, and put the alternative DC responses in the context of wider responses at the distribution network, business unit, and supply chain levels.

The main results of this research can be combined together to form an exploratory framework for selecting the appropriate agile approach, where needed, with respect to DC design and operation. This is set out in Figure 5-6 and involves the following steps:

- *Specify agility requirements.* First of all, the particular types of agility to which the supply chain may need to respond should be identified by using the five types of agility (and sub-categories) outlined in Table 5-1 above. The possible range (e.g. the percentage uplifts and downturns to demand patterns), the required response time to the variance (e.g. one hour, one day or one month notice), and the service level uniformity requirement (e.g. to maintain 99.5% accuracy during peak) should all be defined for handling the type of variance in question.
- *Identify resource options.* The resource options at the DC level can be categorised into land / buildings, equipment, staff and processes / systems. These options need to be combined with possible responses within the wider network at the distribution network, business unit, and supply chain level, as set out in Figure 5-5.
- *Consider alternative approaches.* Possible alternative approaches to each of these resource options should be considered, as per the examples given in Table 5-2. These need to be checked against the agility requirements specified in the first step above, as each will have different implications in terms of response times, etc.
- *Calculate costs for feasible options.* The capital and operating costs of the feasible options need to be calculated.
- *Select appropriate agile approach.* Based on the above, an appropriate agile approach can then be identified and adopted.

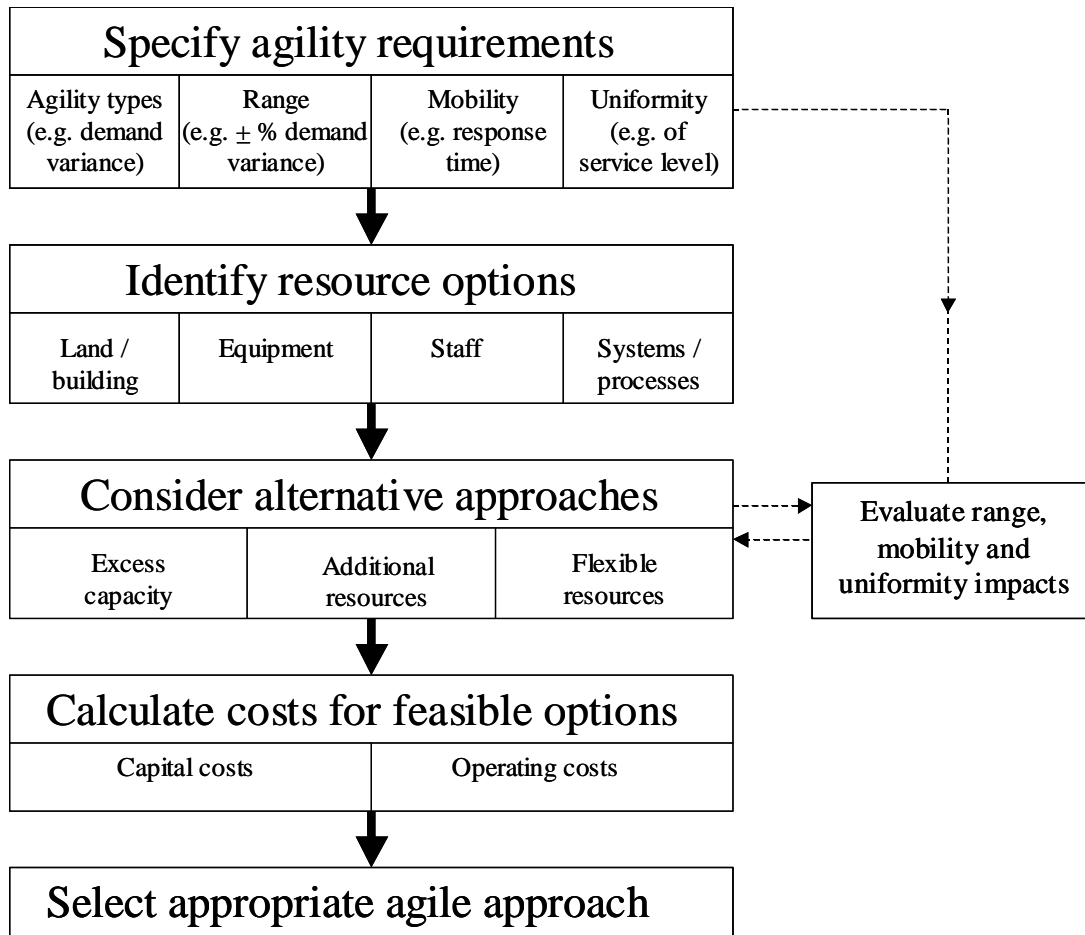


Figure 5-6 Methodology for selecting the appropriate agile approach to DC design and operation

The challenge for DC designers and operators is how to provide the range of agility required at minimal additional capital or unit operating costs, with little time delay and with no deterioration in customer service levels. These can therefore form the basis for the measurement of agility at the DC level, and can be categorised in the same way as the dimensions identified for manufacturing flexibility by Upton (1994), as shown in Table 5-3.

Measurement Category	Key Performance Indicator	Examples
Range	<ul style="list-style-type: none"> Agility types that can be handled Variance that can be handled 	<p>Volume: demand variance</p> <p>$\pm 50\%$ of average throughput</p>
Mobility	<ul style="list-style-type: none"> Capital cost Unit operating cost Time 	<p>Extra cost of sorter capacity, over and above that needed normally</p> <p>Extra cost of temporary staff per unit throughput</p> <p>The length of time needed to hire additional fork-lift trucks</p>
Uniformity	<ul style="list-style-type: none"> Performance Service level 	<p>Lower productivity and/or accuracy of temporary staff (reflected in KPIs above and below)</p> <p>On-Time In Full (OTIF) service level provided to customers during peak compared to average throughputs</p>

Table 5-3 Key performance indicators (KPIs) for measuring DC agility

The measurement of agility is thus a dynamic one, using KPIs to compare performance at times of variance with that observed during normal, or average, periods. This is in contrast to the normal KPIs used in measuring DC performance (e.g. as set out by Frazelle, 2002a) which measure static performance across a period or at a point in time.

This approach to agility at the DC level needs to be incorporated into an overall warehouse design methodology. The typical warehouse design steps listed in section 2.4 (from Rushton *et al.*, 2000) thus need to be refined and clarified to make explicit how flexibility should be incorporated into the design. As a first suggestion for this, the author of this thesis has incorporated scenario planning and the evaluation of design flexibilities into the subsequent edition (i.e. Rushton *et al.*, 2006). The relevant steps are:

- *Define business requirements and design constraints.* The business requirement is not regarded as a single plan within this but as a range of future scenarios that the warehouse should be designed to meet. This reflects the approach advocated by Sodhi (2003) for supply chain planning in general.
- *Evaluate design flexibilities:* This additional step is based on the different types of agility and the different ways of providing this agility, as presented within this research.

These are incorporated into the full design steps in Rushton *et al.* (2006), as follows:

- Define business requirements and design constraints (including scenario planning)
- Define and obtain data
- Formulate a planning base
- Define the operational principles
- Evaluate equipment types
- Prepare internal and external layouts
- Draw up high-level procedures and information systems requirements
- Evaluate design flexibility
- Calculate equipment quantities
- Evaluate the design against system requirements and constraints (including the business scenarios)
- Finalise the preferred design

These steps thus extend the conventional warehouse design framework to include the provision of supply chain agility at the DC level.

5.4 Distribution centre automation (paper 5)

The findings of the research into warehouse automation identified that the accommodation of growth is a prime reason for automation, in addition to the cost and service reasons previously identified by Dadzie and Johnston (1991). Growth may arise for a number of reasons and whilst Hackman *et al.* (2001) found some possible inefficiencies associated with automated warehouses, Pfohl *et al.* (1992) considered that automation is partly able to offset the higher operating costs that would otherwise result from the increased complexity and distances of large warehouses. The benefits of large warehouses may thus be found in the wider supply chain (e.g. through inventory consolidation) and automation may facilitate these by mitigating potential diseconomies of scale.

As noted earlier, there is however concern about the inflexibility of warehouse automation and therefore this may not fit well with the concept of supply chain agility. The research found that the timescales for implementation were fairly lengthy with the average project timescale (from the start of planning to the project going live) being 20 months, ranging from 5 months for the shortest to 39 months for the longest in the sample. In addition, there is an average of a further 3 months for the 'ramp up' of the operation from the initial go-live to full throughput levels being achieved, ranging from an immediate 'big bang' approach to a 'ramp-up' of over one year. This gives a total average time span of almost two years and therefore there needs to be some business certainty as to the future supply chain requirement for automation to be appropriate.

In addition, the research highlighted the extent of the disruption of automation projects to the ongoing operations, with only 5 of the 24 projects researched reporting no disruption. Of the remainder, 11 operations experienced minimal disruption and 8 projects suffered from moderate or extensive disruption. The information technology

systems and the equipment installation were cited as the two principal reasons for these disruptions. Although automated equipment is now fairly mature and reliable, it was identified that there were many strands to implementation projects (for example, building construction, automated equipment, information technology systems, retraining of personnel, co-ordination between sites affected, and overall project management) and the interaction of these gave rise to considerable complexity and the potential for disruption. There is thus a need to plan carefully for the management of the ongoing operation if a service level dip is not to be experienced. Such a service level dip is shown conceptually in Figure 5-7. In this hypothetical situation, automation is being introduced to improve service levels, but, as demonstrated by the survey findings, there is a real risk of the service level diminishing immediately after commissioning before rising towards the desired level.

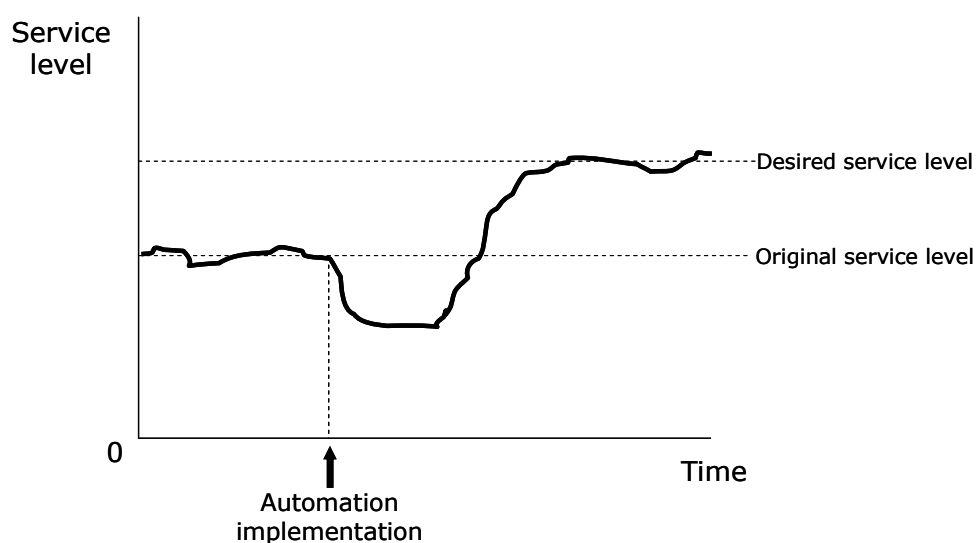


Figure 5-7 Service level dip, potentially arising from warehouse automation projects

Following implementation, many of the perceived challenges of the respondents were concerned with flexibility, including, for example, the possible future need to accommodate a wider product range or to reduce lead times further. Interestingly, the typical project steps identified during the research started with the 'business requirement' but did not specifically include scenario planning. Sensitivities are often considered (e.g. by means of simulation) later in the implementation project to understand how robust the selected solution may be, but there does not appear to be a full consideration of alternative scenarios from a wider business perspective (e.g. the takeover of a potential competitor which may double the throughput, or entry into the home internet shopping arena which may create a need for item level picking).

6 CONCLUSIONS AND RESEARCH AGENDA

6.1 Research focus

The concept of supply chain agility has been developed in recent years but chiefly at a fairly high level, for example at the network and organisational levels. There has been very little consideration to supply chain agility at the operational level, particularly with regard to distribution centres. These assets are long term in nature and therefore present a real challenge to operationalising supply chain agility. In fact, the existing literature is rather equivocal as to whether there should be any distribution centres at all within agile supply chains, and, if so, what role they should perform. It is recognised in much of the literature that markets are becoming increasingly volatile and yet, at the same time, there is evidence that warehousing constitutes a significant percentage of logistics expenditure and some further evidence that the building of large warehouses may be increasing. This is an area that requires greater understanding and is thus the focus of this exploratory research.

The literature review highlighted certain gaps that led to three key research questions. The main conclusions to each of these questions are presented below.

6.2 Is there a role for distribution centres in agile supply chains, and, if so, what is that role, or roles?

The main role of inventory-holding distribution centres in agile supply chains can be linked to the concept of decoupling points. In the literature, these points are described as holding strategic inventory in order to separate lean upstream (e.g. production) flows from the volatile flows required by the market place. The upstream flows are generally planned to forecast whereas the flows downstream of the decoupling point are normally based on actual demand. For these decoupling points to be appropriate, it is concluded that two conditions should hold:

- the supplier lead time should be greater than the customer lead time (i.e. a 'lead time gap')
- the demand for the product should be continual (i.e. product lines that need to be replenished; not one-off 'fashion' lines)

If the first condition does not apply, then goods can be supplied to order without the need for inventory. If the second condition does not apply, then goods can be despatched directly to shops for sale without the need to hold any inventory in distribution centres, as once the goods are sold the next fashion line is then passed through the supply chain to the shops.

In these make-to-order and fashion scenarios, distribution centres may play a role in cross-docking to facilitate rapid transport flows. Similarly, within inventory holding scenarios, goods may be cross-docked through distribution centres both upstream and downstream of the decoupling point in order to consolidate loads from suppliers, facilitate transport movements or assemble complete orders for customers.

Distribution centres may also play a role in other aspects of agility, such as production postponement. This may be significant, for example in terms of reducing the number of stock keeping units by labelling and kitting. However, the survey results indicate that these activities are fairly simple and can often take place as part of the pick and pack operation, rather than being substantive production assembly facilities.

Distribution centres may combine a number of these roles. For example, distribution centres at ports may deconsolidate container shipments, palletise the goods, and feed them through to the main decoupling point DC as required. Such distribution centres thus combine some aspects of inventory holding (as an overflow of the main decoupling point), logistics postponement, and goods preparation.

Although this research has only examined outbound flows, the handling of returned goods is another role that could be included within the context of agility. For example, distribution centres may be required to handle the return of unwanted goods, damaged goods, unsold goods, goods requiring recovery (e.g. electrical and electronic goods), and packaging.

The main roles of distribution centres can be identified by taking into account the business model, possible inventory reduction strategies, risk mitigation, supply chain trade-offs, and inventory optimisation. An exploratory framework for this is set out in Figure 5-2. It is intended that this framework can refocus attention on identifying the appropriate nature and level of resources for these important aspects of logistics rather than considering inventory and warehousing as necessarily undesirable.

Based on this research, the appropriate roles of distribution centres can be mapped onto existing frameworks of supply chain taxonomy, such as that by Christopher *et al.* (2006), as in Figure 5-4.

6.3 How can distribution centres be designed and operated to support agile supply chains? In particular, what is the role of automation?

The key frameworks from this research can be linked together to form an overall, albeit still exploratory, methodology for the development of supply chain agility at the DC level. It is intended that this would form a useful first step both for practitioners who need to meet the demands of agility at the DC level and for researchers in examining further this important aspect of supply chains. This overall methodology is shown in Figure 6-1.

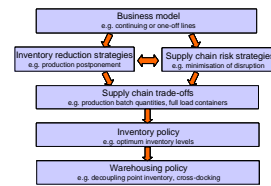
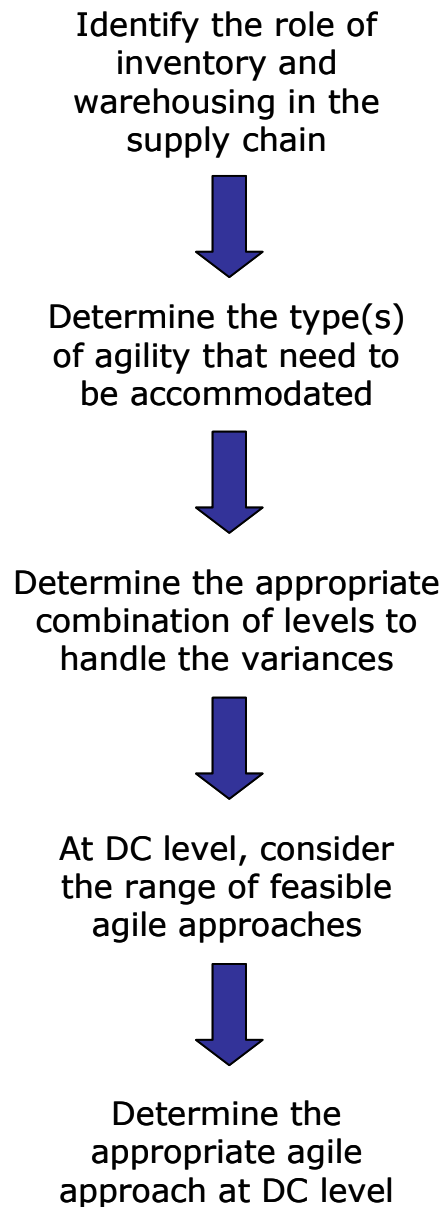


Figure 5-2

Classification	Sub-classification
Volume	<ul style="list-style-type: none"> • Demand variance • Growth • Seasonality
SKU volume	<ul style="list-style-type: none"> • Demand variance • Life cycles • Penetration
Time	Order cycle (e.g. rush orders)
Unit quantity	Items vs. cases vs. pallets
Presentation	Preparation of goods for dispatch (e.g. specific pallet heights)
Information	Electronic (e.g. RFID)
	Physical (e.g. labels)

Table 5-1

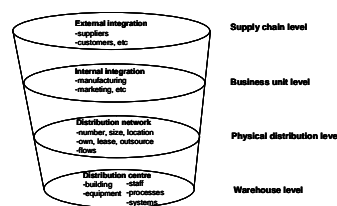


Figure 5-5

	Extra capacity	Additional resources needed	Flexible resources
Load / building	Available height for storage Increase in floor area Increase in floor area	Using external space Using external space as a shared user DC	Flexi-stacking Flexi-stacking Flexi-stacking
Equipment	Conveyor capacity Size of additional stock to receive Stock to receive	Flexi-stacking Flexi-stacking Flexi-stacking	Flexi-stacking Flexi-stacking Flexi-stacking
Staffing	Staffing at various stages of the supply chain Staffing at various stages of the supply chain	Staffing at various stages of the supply chain Staffing at various stages of the supply chain	Staffing at various stages of the supply chain Staffing at various stages of the supply chain
Process / systems	Flexibility of multiple processes Flexibility of multiple processes Flexibility of multiple processes	Flexibility of multiple processes Flexibility of multiple processes Flexibility of multiple processes	Flexibility of multiple processes Flexibility of multiple processes Flexibility of multiple processes

Table 5-2

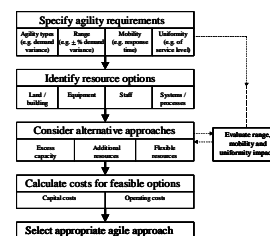


Figure 5-6

Figure 6-1 Overall methodology for the development of supply chain agility at the DC level

Once the role of the distribution centre has been established (as per the framework in Figure 5-2), the different types of agility to which the distribution centre may need to respond should be identified (e.g. by scenario planning). Three types had previously been identified by van Hoek (2001) and these were extended to five types, plus sub-categories, during this research, as detailed in Table 5-1.

The responses to these agility types can be made at a variety of hierarchical levels within the supply chain, from external integration with suppliers and customers, to internal integration with other functions, the distribution network level and within the DCs themselves. Responding to the need for agility at the DC level may thus be one of a combination of levels that should form the appropriate response. This can be represented in a similar way to that identified for manufacturing flexibility by Koste

and Malhotra (1999) – as in Figure 5-5. This diagram is drawn funneling down to the individual DC, but of course there are other operational areas that would need to be considered in parallel, such as manufacturing, marketing, sales and transport, and these would have similar “funnels” (as is the case with manufacturing in Koste and Malhotra, 1999). The last two steps in the methodology are specifically for the DC “funnel”. In a similar way, further steps would be applicable to the parallel areas.

At the DC level, the responses to different types of variance can be categorised into land / buildings, equipment, staffing and process/systems. Each of these can be further categorised into how the provision for flexibility is provided in terms of extra capacity, additional resources when needed, and flexible resources. These two dimensions form a matrix of possible options, as shown in Table 5-2. Each possible solution has different implications for capital cost investment, operating cost, timeframe and service levels.

From this, an exploratory framework is developed for selecting the appropriate agile approach to DC design and operation. This is set out in Figure 5-6, starting with the type of agility required, the degree of variance to be accommodated, the timeframes within which the variances must be accommodated and the service level stipulations. The broad range of options can then be identified and cost comparisons undertaken.

This overall framework can then be utilised within the steps taken for warehouse design as set out in section 5.3. However, for this to be effective, the normal first step of identifying the ‘business plan’ should be extended to include the feasible range of business scenarios that the distribution centre may need to accommodate. This follows the approach put forward by Sodhi (2003) for strategic supply chain planning.

With regard to the role of automation, there is some evidence to suggest that there are diseconomies of scale in warehousing (Hackman *et al.*, 2001) but that automation may help to contain costs as this scale increases (Pfohl *et al.*, 1992). This research has identified that the main reasons for automation are to accommodate growth, reduce costs and improve service. However, there are concerns about the flexibility of automated equipment and this appears to be supported by the survey respondents within this research. In addition, the timescales to implement automated projects are fairly lengthy (an average of almost two years including ‘ramp-up’), which does not fit well with the concept of agility. Furthermore, there is a real danger of a service level dip as soon as these complex projects become operational and this may have a significant impact on responsiveness during this initial period.

The benefits of larger distribution centres thus appear to be in the wider supply chain (e.g. through inventory consolidation and logistics postponement), with automation either enabling growth within an existing DC or containing costs in the building of larger DCs. However, the user needs to be fairly certain of the range of future scenarios to be met to ensure that the automation will meet future needs.

6.4 How can distribution centre agility be measured?

Conventional measures of DC performance are static in nature, recording performance at a point in time or over a period of time. Even for this task, there is

considerable concern about the suitability of these measures, as they are greatly influenced by the operational conditions of a particular distribution centre at a particular time. Hackman *et al.* (2001) conclude that the normal ratio measures (e.g. cost per case, or picks per hour) are not very suitable for comparative purposes. Data Envelopment Analysis (DEA) has been proposed as one solution but this has the disadvantage of requiring a large number of sample distribution centres in relation to the number of inputs and outputs analysed.

With static measures still requiring development, it is probably not surprising that there has been little attention to dynamic performance indicators that can be used to measure agility. However, the framework of manufacturing agility dimensions proposed by Upton (1994) does provide a basis and this research indicates that it can be suitably adapted to the measurement of DC agility. The 'range' dimension can encompass the different types of agility identified during this research as well as the degree of variance that can be accommodated. The 'mobility' dimension can be used to measure both the unit cost impact and the time delay in handling variances as in manufacturing flexibility. The 'uniformity' dimension can be used to examine the impact on both productivity and service levels, again when handling the variances as compared to normal or average situations.

6.5 Theoretical and practical implications

This research has extended the understanding of supply chain agility, particularly with regard to how agility should be operationalised at the distribution centre level. A number of constructs from supply chain agility and manufacturing flexibility have been used, modified, and extended to form a basis for suggesting a series of exploratory frameworks. It is intended that these can form the basis for further research and refinement.

In addition, the results of this research provide an initial means by which firms can evaluate their policies towards DC agility. A network of distribution centres may form a basis for competitive advantage, or disadvantage, as such a network is valuable, rare, inimitable and non-substitutable, in the context of Barney (1991), in the short to medium term. Distribution centre buildings tend to have long asset lives (e.g. 20 to 25 years) whilst the equipment within them, particularly automated equipment, may also have relatively long lives (e.g. 5 to 15 years). Whilst it may be possible to design and build a new distribution centre within 12 to 18 months, the existence of an existing network of DCs that cannot be easily written off financially means that it may be difficult to switch from one network of DCs to another in a short space of time. Distribution centres may therefore act as constraint to, as well as a source of, competitive advantage. The consequences of not incorporating agility into this network can be dramatic as illustrated by a study of "today's dynamic, fast-paced environment" of e-fulfilment operations which concluded that the "suggested design may make or break an e-commerce fulfilment center" (Tarn *et al.*, 2003, p. 360-361).

It is expected that this research will thus form a basis for further research in this important area of supply chain management as well as providing frameworks that will provide practitioners with some insights into how to design, operate and measure distribution centres in agile supply chains.

6.6 Research limitations and areas for further research

The subject of distribution centre agility has been studied very little in the past and therefore this research has been exploratory in nature. In order to gain a rich understanding of the subject area, a case study approach has been used for the central part of the research. This has provided a series of initial frameworks but this is inevitably the start of theory development in this area and much more work needs to be done by, hopefully, many more researchers in the future. By its nature, the approach that has been adopted is limited in scope and therefore the research needs to be extended to cover other aspects of the supply chain (e.g. inbound as well as outbound), industry sectors, DC roles and geographic regions of the world. Whilst the results are intended to provide a useful insight and basis for further understanding, they cannot be generalised with confidence outside the specific contexts described in this thesis.

There is thus a wide range of areas that would be useful to examine further. Some of the more important areas are as follows:

- *DC agility.* This research has been exploratory in nature and therefore further research is required to validate and develop the findings. This should include:
 - *theory development:* to validate and develop the overall methodology (shown in Figure 6-1) further. One approach to this would be by action research to use this methodology in case study organisations to ascertain in real-life situations whether it provides a useful means of developing supply chain agility at the DC level and to refine it as appropriate. This could be undertaken across a cross-section of situations (e.g. based on the taxonomy of Christopher *et al.*, 2006) so as to gain an understanding of the different operational circumstances that may impact on the frameworks proposed.
 - *roles:* to research agile responses specifically related to the different DC roles identified (e.g. storage, cross-docking and postponement).
 - *industry sectors and geography:* to identify the varying requirements in different industry sectors, geographic regions of the world, and sections of the supply chain (e.g. inbound as well as outbound).
- *Warehouse design methodology.* It is recognised that there needs to be a comprehensive methodology for the design of warehouses (Rouwenhorst *et al.*, 2000 and Goetschalckx *et al.*, 2002). This research has provided a small input into this but a science-based methodology still needs to be developed. Possible approaches to this include ethnographic studies (as used by Govindaraj *et al.*, 2000) and modelling.
- *Performance measurement.* The subject of DC performance measurement, both in static and dynamic situations, still requires further development. Research is required to identify the key parameters that impact on performance (e.g. order profiles and scale of operations) so that meaningful

comparative measures can be developed. A survey methodology may be appropriate for this, possibly in conjunction with modelling DC operations.

The author is continuing to research this area and currently has papers submitted with academic journals that (i) examine DC agility in Central Europe and (ii) review approaches to DC design. It is hoped that this series of publications will lead to further interest and development in this important area of supply chains.

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Pollitt, D. (2006). Interim management helps Carphone warehouse to get TalkTalk on track: Fast recruitment focuses specialist skills where they are most needed. *Human Resource Management International Digest*, 14(4), p. 10-12.

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Rushton, A., Croucher, P. and Baker, P. (2006). *The Handbook of Logistics and Distribution Management*, 3rd ed. Kogan Page, London.

Sainsbury, J., PLC, (2004). *Annual Report and Financial Statements*.

Sanders, N. R. and Ritzman, L. P. (2004). Using warehouse workforce flexibility to offset forecast errors. *Journal of Business Logistics*, 25(2), p. 251-269.

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Wilhelm, W., Liang, D., Rao, B., Warriar, D., Zhu, X. and Bulusu, S. (2005). Design of international assembly systems and their supply chains under NAFTA. *Transportation Research Part E: Logistics and Transportation Review*, 41(6), p. 467-493.

Womack, J.P. and Jones, D.T. (1996). *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*. Simon & Schuster, London.

Yao, A.C. and Carlson, J.G.H. (2003). Agility and mixed-model furniture production. *International Journal of Production Economics*, 81-82, p. 95-102.

Yin, R. K. (2003). *Case Study Research: Design and Methods*, 3rd ed. Sage, Thousand Oaks.

Yusuf, Y.Y., Sarhadi, M. and Gunasekaran, A. (1999). Agile manufacturing: The drivers, concepts and attributes. *International Journal of Production Economics*, 62, p. 33-43.

Zhang, Q., Vonderembse, M. A. and Lim, J-S. (2002). Value chain flexibility: A dichotomy of competence and capability, *International Journal of Production Research*, 40(3), p. 561-583.

APPENDIX A: Results of database search on link between distribution centres and agility / flexibility

Note: Search String DC = 'distribution cent*' OR warehous* (AND NOT 'data warehous*'), where * = any combination of letters.

Paper	Database	Search String
Benjamin, J. D., Zietz, E. N. and Sirmans, G. S. (2003). The environment and performance of industrial real estate. <i>Journal of Real Estate Literature</i> , 11(3), p. 279.	Proquest	DC + flexibility
Ciscel, D. H. and Smith, B. E. (2005). The impact of supply chain management on labor standards: The transition to incessant work. <i>Journal of Economic Issues</i> , 39(2), p. 429-437.	Proquest	DC + flexibility
de Koster, M. B. M. and Warffemius, P. M. J. (2005). American, Asian and third-party international warehouse operations in Europe: A performance comparison. <i>International Journal of Operations & Production Management</i> , 25(7/8), p. 762-780.	Proquest	DC + flexibility
Gunasekaran, A., Tirtiroglu, E. and Wolstencroft, V. (2002). An investigation into the application of agile manufacturing in an aerospace company. <i>Technovation</i> , 22(7), p. 405-415.	Science Direct	DC + agility DC + flexibility
Hassan, M. M. D. (2002). A framework for the design of warehouse layout. <i>Facilities</i> , 20(13/14), p. 432-440.	Emerald	DC + flexibility
Heaps, P. (2005). Retail warehousing, shopping parks and leisure. <i>Journal of Retail & Leisure Property</i> , 4(2), p. 174-180.	Proquest	DC + flexibility
Heaps, P. and Mather, J. (2005). Retail warehouse and shopping park development pipeline: Those who will occupy new space and the prevailing investment market. <i>Journal of Retail & Leisure Property</i> , 4(4), p. 352-358.	Proquest	DC + flexibility
Hui-Ming, W., Kalwani, M. U. and Akcura, T. (2007). A Bayesian multivariate Poisson regression model of cross-category store brand purchasing behavior. <i>Journal of Retailing and Consumer Services</i> , In Press, Corrected Proof, Available online.	Science Direct	DC + flexibility
Jayaraman, V. (1998). An efficient heuristic procedure for practical-sized capacitated warehouse design and management. <i>Decision Sciences</i> , 29(3), p. 729-745.	Proquest	DC + flexibility

Hyland, P. W., Soosay, C. and Sloan, T. R. (2003). Continuous improvement and learning in the supply chain. <i>International Journal of Physical Distribution & Logistics Management</i> , 33(4), p. 316-335.	Proquest	DC + agility DC + flexibility
Kippenberger, T. (1997). A cola's cans long and weary journey. <i>The Antidote</i> , 2(5), p. 15-16.	Emerald	DC + flexibility
Kuehn, A. A. and Hamburger, M. J. (1963). A heuristic program for locating warehouses. <i>Management Science</i> , 9(4), p. 643-666.	Proquest	DC + flexibility
Larson, P. D. and Gammelgaard, B. (2001). The logistics triad: Survey and case study results. <i>Transportation Journal</i> , 41(2/3), p. 71-82.	Proquest	DC + flexibility
Nellist, D. (1992). Quality Teamwork at Wakefield - Coca-Cola & Schweppes Beverages Ltd: Wakefield Factory. <i>Industrial Management + Data Systems</i> , 92(2), p. 21-23.	Proquest	DC + flexibility
Parry, N. (1992). Warehouse and distribution centre. <i>Logistics Information Management</i> , 5(4), p. 8-9.	Proquest	DC + flexibility
Pires, J. N. (2005). Interfacing industrial robotic systems with manufacturing tracking and control software: a choice for semi-autonomous manufacturing systems. <i>Industrial Robot: An International Journal</i> , 32(3), p. 214-219.	Emerald	DC + agility DC + flexibility
	Proquest	DC + agility DC + flexibility
Pollitt, D. (2006). Interim management helps Carphone warehouse to get TalkTalk on track: Fast recruitment focuses specialist skills where they are most needed. <i>Human Resource Management International Digest</i> , 14(4), p. 10-12.	Emerald	DC + flexibility
	Proquest	DC + flexibility
Samaranayake P. (2005). A conceptual framework for supply chain management: a structural integration. <i>Supply Chain Management: An International Journal</i> , 10(1), p. 47-59.	Emerald	DC + flexibility
	Proquest	DC + flexibility
Sanders, N. R. and Ritzman, L. P. (2004). Using warehouse workforce flexibility to offset forecast errors. <i>Journal of Business Logistics</i> , 25(2), p. 251-269.	Proquest	DC + flexibility
Smagalla, D. (2004). Supply-chain culture clash. <i>MIT Sloan Management Review</i> , 46(1), p. 6.	Proquest	DC + flexibility
Steudel, H. J. (1979). Generating pallet loading patterns: A special case of the two-dimensional cutting stock problem. <i>Management Science</i> , 25(10), p. 997-1004.	Proquest	DC + flexibility

Szymanski, R. (1995). The well-planned menu - Logistics for an airline catering company. <i>Logistics Information Management</i> , 8(3), p. 43-44.	Proquest	DC + flexibility
van Oudheusden, D. L. and Boey, P. (1994). Design of an automated warehouse for air cargo: The case of. <i>Journal of Business Logistics</i> , 15(1), p. 261-285.	Proquest	DC + flexibility
Vermeulen, C. A. P. (1993). Going Dutch: A recipe for value-added logistics. <i>The Journal of European Business</i> , 4(3), p. 26-29.	Proquest	DC + flexibility

APPENDIX B: Results of database search on link between distribution centres and supply chain strategy / management

Note on Search Strings:

DC = 'distribution cent*' OR warehous* (AND NOT 'data warehous*')

SCS = 'supply chain strateg*'

SCM = 'supply chain management'

where * = any combination of letters.

Paper	Database	Search String
Anonymous. (2004). Supply chain innovation. <i>International Journal of Productivity and Performance Management</i> , 53(3/4), p. 377-378.	Proquest	DC + SCM
Anonymous. (2006). Annotated bibliography of supply chain management and logistics-related dissertations: Warehousing & storage (code 10). <i>Journal of Business Logistics</i> , 27(1), p. 245-248.	Proquest	DC + SCM
Aptel, O. and Pourjalali, H. (2001). Improving activities and decreasing costs of logistics in hospitals: a comparison of U.S. and French hospitals. <i>The International Journal of Accounting</i> , 36(1), p. 65-90.	Science Direct	DC + SCM
Atkinson, W. (2004). Tagged: The risks and rewards of RFID technology. <i>Risk Management</i> , 51(7), p. 12-17.	Proquest	DC + SCM
Bourlakis, M.A. and Bourlakis, C.A. (2001). Deliberate and emergent logistics strategies in food retailing: A case study of the Greek multiple food retail sector. <i>Supply Chain Management: An International Journal</i> , 6(4), p. 189-200.	Emerald	DC + SCM
	Proquest	DC + SCM
Buxey, G. (2006). Reconstructing inventory management theory. <i>International Journal of Operations & Production Management</i> , 26(9), p. 996-1012.	Emerald	DC + SCM
Caputo, A.C., Pelagagge, P. M. and Scacchia, F. (2003). Integrating transport systems in supply chain management software tools. <i>Industrial Management & Data Systems</i> , 103(7), p. 503-515.	Emerald	DC + SCM
	Proquest	DC + SCM
Carter, C.R., Ellram, L.M. and Tate, W. (2007). The use of social network analysis in logistics research. <i>Journal of Business Logistics</i> , 28(1), p. 137-169.	Proquest	DC + SCM
Chen, M-C. and Wu, H-P. (2005). An association-based clustering approach to order batching considering customer demand patterns. <i>Omega</i> , 33(4), p. 333-343.	Science Direct	DC + SCM
Chen, Z-L. and Pundoor, G. (2006). Order assignment and scheduling in a supply chain. <i>Operations Research</i> , 54(3), p. 555-574.	Proquest	DC + SCM

Choy, K.L., Lee, W.B. and Lo V. (2004). An enterprise collaborative management system – a case study of supplier relationship management. <i>Journal of Enterprise Information Management</i> , 17(3), p. 191-207	Emerald	DC + SCM
Ciscel, D.H. and Smith, B. E. (2005). The impact of supply chain management on labor standards: The transition to incessant work. <i>Journal of Economic Issues</i> , 39(2), p. 429-437.	Proquest	DC + SCM
Corsi, T.M., Boyson, S., Verbraeck, A., Van Houten, S-P., Han, C. and MacDonald, J. R. (2006). The real-time global supply chain game: New educational tool for developing supply chain management Professionals. <i>Transportation Journal</i> , 45(3), p. 61-73.	Proquest	DC + SCM
Davis, T. (1993). Effective supply chain management. <i>Sloan Management Review</i> , 34(4), p. 35-46.	Proquest	DC + SCM
Ellinger, A.E., Ellinger, A.D. and Keller, S. B. (2005). Supervisory coaching in a logistics context. <i>International Journal of Physical Distribution & Logistics Management</i> , 35(9), p. 620-636.	Emerald	DC + SCM
Ericson, J. (2006). Lean inspection through supplier partnership. <i>Quality Progress</i> , 39(11), p. 36-41.	Proquest	DC + SCM
Fassoula, E.D. (2006). Transforming the supply chain. <i>Journal of Manufacturing Technology Management</i> , 17(6), p. 848-860.	Emerald	DC + SCM
Fox., M. S., Barbuceanu, M. and Teigen, R. (2000). Agent-oriented supply-chain management. <i>International Journal of Flexible Manufacturing Systems</i> , 12(2/3), p.165-188.	Proquest	DC + SCM
Goh, M. and Pinaikul, P. (1998). Logistics management practices and development in Thailand. <i>Logistics Information Management</i> , 11(6), p. 359-369.	Emerald Proquest	DC + SCM DC + SCM
Green, F. B. (2001). Managing the unmanageable: integrating the supply chain with new developments in software. <i>Supply Chain Management: An International Journal</i> , 6(5), p. 208-211.	Emerald Proquest Proquest	DC + SCM DC + SCS DC + SCM
Hancock, J. and Oates, S. (2001). Minding other people's business: perspectives on outsourcing at Bradford & Bingley. <i>Supply Chain Management: An International Journal</i> , 6(2), p. 58-59.	Emerald Proquest	DC + SCM DC + SCM
Hughes, R.A. (2006). One on one. <i>Journal of Supply Chain Management</i> , 42(2), p. 2-3.	Proquest	DC + SCM
Hull, B. (2001). A structure for supply-chain information flows and its application to the Alaskan crude oil supply chain. <i>Logistics Information Management</i> , 15(1/2), p. 8-23.	Proquest	DC + SCM
Huntress, K. (2004). Evolution in the demand and supply planning at Dow Corning. <i>The Journal of Business Forecasting Methods & Systems</i> , 23(4), p. 10-15.	Proquest	DC + SCM

Jain, A. and Moinzadeh. (2005). A supply chain model with reverse information exchange. <i>Manufacturing & Service Operations Management</i> , 7(4), p. 360-378.	Proquest	DC + SCM
Janssen, M. (2004). Insights from the introduction of a supply chain co-ordinator. <i>Business Process Management Journal</i> , 10(3), p. 300-310.	Emerald	DC + SCM
Juran, D.C. and Dershin, H. (2000). Lessons in supply chain assessment and improvement. <i>Quality Focus</i> , 4(1), p. 18-27.	Proquest	DC + SCM
Kadiyala, R. and Kleiner, B. H. (2005). New developments concerning business information Systems. <i>Management Research News</i> , 28(11/12), p. 164-170.	Proquest	DC + SCM
Kärkkäinen, M. and Holmström J. (2002). Wireless product identification: enabler for handling efficiency, customisation and information sharing. <i>Supply Chain Management: An International Journal</i> , 7(4), p. 242-252.	Emerald Proquest	DC + SCM DC + SCM
Keegan, J., O'Callaghan, E. and Wilcox, M. (2001). Facilitators and inhibitors of supply chain innovation - prospects for supply chain management in the Irish grocery sector. <i>Irish Marketing Review</i> , 14(2), p. 26-38.	Proquest	DC + SCM
Kiefer, A.W. and Novack, R.A. (1999). An empirical analysis of warehouse measurement systems in the context of supply chain implementation. <i>Transportation Journal</i> , 38(3), p. 18-27.	Proquest	DC + SCM
Kiely, D.A. (1998). Synchronizing supply chain operations with consumer demand using customer data. <i>The Journal of Business Forecasting Methods & Systems</i> , 17(4), p. 3-9.	Proquest	DC + SCM
Lancioni, R.A., Smith, M.F. and Oliva, T.A. (2000). The role of the Internet in supply chain management. <i>Industrial Marketing Management</i> , 29(1), p. 45-56.	Science Direct	DC + SCM
Lankford, W.M. (2004). Supply chain management and the Internet. <i>Online Information Review</i> , 28(4), p. 301-305.	Emerald Proquest	DC + SCM DC + SCM
Lashine, S.H., Fattouh, M. and Issa, A. (2006). Location/allocation and routing decisions in supply chain network design. <i>Journal of Modelling in Management</i> , 1(2), p. 173-183.	Emerald	DC + SCM
Logan Jr., H. R. (2001). Controlling the uncontrollable. <i>Strategic Finance</i> , 82(10), p. 56-60.	Proquest	DC + SCM
Mason, S.J., Ribera, P. M., Farris, J. A. and Kirk, R. G. (2003). Integrating the warehousing and transportation functions of the supply chain. <i>Transportation Research Part E: Logistics and Transportation Review</i> , 39(2), p. 141-159.	Science Direct	DC + SCM

Min, H. and Melachrinoudis, E. (1999). The relocation of a hybrid manufacturing/distribution facility from supply chain perspectives: a case study. <i>Omega</i> , 27(1), p. 75-85.	Science Direct	DC + SCM
Munson, C. L., Hu, J. and Rosenblatt, M.J. (2003). Teaching the costs of uncoordinated supply chains. <i>Interfaces</i> , 33(3), p. 24 -39.	Proquest	DC + SCM
Perry, R. (1996). Look before you leap. <i>Logistics Information Management</i> , 9(2), p. 36-39.	Emerald	DC + SCS
Petersen, C. G. (2002). Considerations in order picking zone configuration. <i>International Journal of Operations & Production Management</i> , 22(7), p.793-806.	Emerald	DC + SCM
Petersen, C.G., Siu, C. and Heiser, D.R. (2005). Improving order picking performance utilizing slotting and golden zone storage. <i>International Journal of Operations & Production Management</i> , 25(10), p. 997-1012.	Emerald Proquest	DC + SCM DC + SCM
Rae-Smith, J. B. and Ellinger, A.E. (2002). Insight from the introduction of an online logistics service system. <i>Supply Chain Management</i> , 7(1), p. 5-11.	Proquest	DC + SCM
Ranky, P.G. (2006). An introduction to radio frequency identification (RFID) methods and solutions. <i>Assembly Automation</i> , 26(1), p. 28-33.	Emerald	DC + SCM
Rao, B. (1999). The Internet and the revolution in distribution: a cross-industry examination. <i>Technology in Society</i> , 21(3), p. 287-306.	Science Direct	DC + SCM
Samaranayake, P. (2005). A conceptual framework for supply chain management: a structural integration. <i>Supply Chain Management: An International Journal</i> , 10(1), p. 47-59.	Emerald Proquest	DC + SCM DC + SCM
Sarkis, J., Meade, L.M. and Talluri, S. (2004). E-logistics and the natural environment. <i>Supply Chain Management: An International Journal</i> , 9(4), p. 303-312.	Emerald Proquest	DC + SCM DC + SCM
Stock, J.R. and Broadus, C.J. (2006). Doctoral research in supply chain management and/or logistics-related areas: 1999-2004. <i>Journal of Business Logistics</i> , 27(1), p. 139-152.	Proquest	DC + SCM
Tracey, M., Lim, J-S. and Vonderembse, M.A. (2005). The impact of supply-chain management capabilities on business performance. <i>Supply Chain Management: An International Journal</i> , 10(3), p. 179-191.	Emerald Proquest	DC + SCM DC + SCM
Tseng, M-F. (2005). The study of computer assisted learning platform for supply chain inventory Management. <i>The Business Review</i> , 4(1), p. 61-66.	Proquest	DC + SCM
Twist, D.C. (2005). The impact of radio frequency identification on supply chain facilities. <i>Journal of Facilities Management</i> , 3(3), p. 226-239.	Emerald	DC + SCM

van Hoek, R. I. (2000). The purchasing and control of supplementary third-party logistics services. <i>Journal of Supply Chain Management</i> , 36(4), p. 14-26.	Proquest	DC + SCM
Vijayaraman, B. S. and Osyk, B.A. (2006). An empirical study of RFID implementation in the warehousing industry. <i>The International Journal of Logistics Management</i> , 17(1), p. 6-20.	Emerald	DC + SCM
Voss, D., Calantone, R.J. and Keller, S.B. (2005). Internal service quality: Determinants of distribution center performance. <i>International Journal of Physical Distribution & Logistics Management</i> , 35(3), p. 161-176.	Emerald Proquest	DC + SCM DC + SCM
Wilding, R.D. (1998). Chaos theory: Implications for supply chain management. <i>The International Journal of Logistics Management</i> , 9(1), p. 43-56.	Emerald	DC + SCM
Wilhelm, W., Liang, D., Rao, B., Warriar, D., Zhu, X. and Bulusu, S. (2005). Design of international assembly systems and their supply chains under NAFTA. <i>Transportation Research Part E: Logistics and Transportation Review</i> , 41(6), p. 467-493.	Science Direct	DC + SCS
Williams, T. (1997). Realizing the potential benefits of real-time, online data exchange. <i>Supply Chain Management: An International Journal</i> , 2(4), p. 134-136.	Emerald	DC + SCM

APPENDIX C: Survey form used for exploration of the current situation (in Paper 1)

APPENDIX D: Questionnaire used for examining the role of distribution centres (in Paper 2)

The Role of Inventories and Warehouses in International Supply Chains

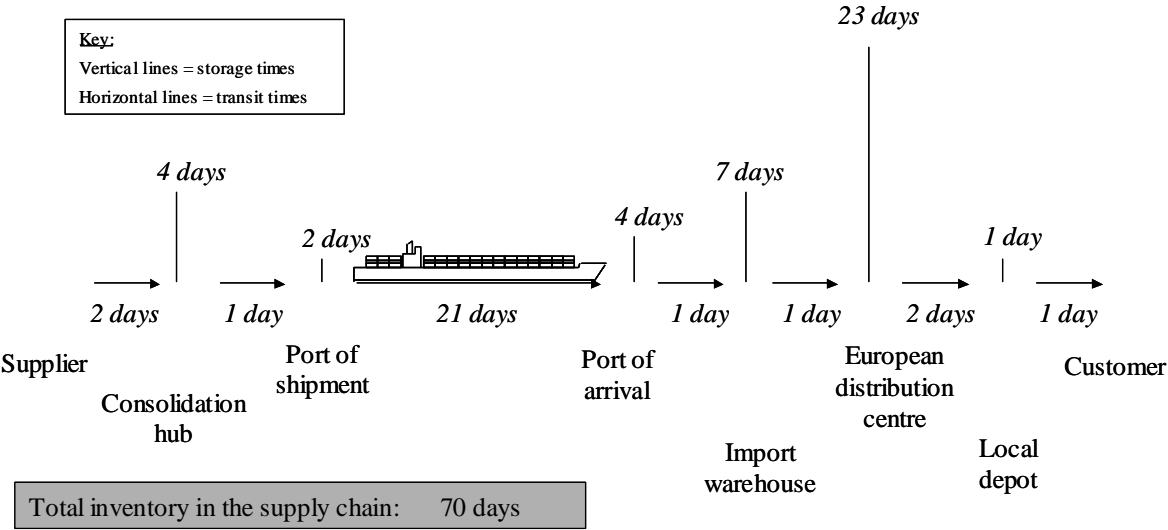
Survey Questions

Supply Chain Map

The research is based on an initial view of the various supply chains using a mapping technique. This technique has been found to be very useful both for analysis purposes and for companies to gain a fuller understanding of their own supply chains. It would be very helpful if all survey participants could select two international supply chains and complete a “supply chain map” for each, in advance, as per the example attached. Ideally, these should have different transit times (e.g. Far East – Western Europe and Eastern Europe – Western Europe routes), but this is not essential.

Outline of supply chain (e.g. *toys from manufacturer to shops; China to U.K.*)

Example supply chain map:



For each transport leg, please indicate the mode and nature of transport: e.g. for the above example, it may be: *truck (palletised); truck (full load container: FCL); ship (FCL); truck (FCL); truck (palletised); truck (palletised); truck (loose).*

For each inventory point, please indicate what type of company operates the warehouse and its purpose: e.g. for the above example, it may be:

Freight forwarder (consolidation); port (awaiting shipment); port (customs clearance); third party logistics company (container unloading and inward flow control); retailer (safety stock); retailer (cross docking).

--

For each of the two supply chains, please state:

- The nature of the supply chain (e.g. make-to-order / make-to-stock).

--

- The supplier lead time(s) and the customer lead time(s) offered (i.e. from order to receipt). For example, you may typically need to place orders on the supplier 8 weeks in advance, but deliver to customers on a next day basis.

Supplier lead time:	
Customer lead time:	

Supply chain risk

In terms of the logistics movement and inventory holdings (i.e. not supplier risks), what do you consider are the main sources of risk? Please show on the table below:

Supply chain risk	Nature of impact on business	Severity of potential impact on business ⁽¹⁾	Likelihood of occurrence ⁽²⁾	Avoidance actions

(1) Show on a scale of 1 to 5: 1= very low impact; 2= low impact; 3= moderate impact; 4= high impact; 5= very high impact.

(2) Show on a scale of 1 to 5: 1= very unlikely to occur in a single year; 2= unlikely to occur in a single year; 3= on average, likely to occur about once in a single year; 4= likely to occur more than once in a single year; 5= very likely to occur multiple times in a single year.

In particular, to what extent do you consider inventory in the supply chain as a potential source of risk (e.g. reduces response to market changes, or leads to obsolescence) and/or as a risk avoidance mechanism (e.g. to buffer against a surge in demand or against a delay in supply)?

APPENDIX E: Semi-structured interview forms and Likert scales used with DC designers (in Paper 3)

Designing distribution centres for agile supply chains

Description of distribution centre

- Company & location
- Industry
- Geographic coverage
- Role in supply chain
- Size/height
- Pallet spaces
- Number of SKUs
- Outline design sketch

Flexibility required

Volume	Degree of agility
- Growth	
- Seasonality	
- Promotions	
- Life cycles	
- Demand variance	
Time	
- Rush orders	
Quantities	
- Units vs cases vs pallets	
Presentation	
- Outbound	
Information	
- Customised information	
Inbound	
- Volume/time	
- Units vs cases vs pallets	
- Presentation	
- Information	
Returns	
- Returned goods	

Key: Results show the degree of agility perceived as being needed on a Likert scale of 1 to 5:

5 = “very high”, 4 = “high”, 3 = “average”, 2 = “low”, 1 = “very low or none”.

For each type of flexibility: nature of competency used.

Distribution centre competency
- building
- equipment
- staff
- process
- systems

Cost, for provision of agile capability

Capital cost	Operating cost	Cost comparison to non-agile capability
-3	-3	Much lower cost
-2	-2	Moderately lower cost
-1	-1	Slightly lower cost
0	0	Same cost
1	1	Slightly higher cost
2	2	Moderately higher cost
3	3	Much higher cost

Mobility, in terms of time to switch to handling variance from norm

Likert score	Time-span
0	Immediate
1	Short-term
2	Medium-term
3	Long-term

Uniformity, in terms of service levels, when handling variance compared to norm.

Likert score	Uniformity
0	Same service level
1	Slightly lower
2	Moderately lower
3	Much lower

APPENDIX F: Semi-structured interview forms and Likert scales used with DC operators (in Paper 4)

The interrelationship between supply chain strategy and warehousing capabilities

Research Project Outline

Peter Baker
Cranfield Centre for Logistics and Supply Chain Management

Introduction

There has been much interest, both in businesses and in academic circles, about supply chain strategy and particularly in concepts such as Collaborative Planning Forecasting and Replenishment (CPFR), Efficient Consumer Response (ECR) and Just In Time (JIT). However, there has been relatively little discussion about the implications of these concepts on warehouses – for example, exactly how warehouses should be designed and operated to meet these requirements or, indeed, what constraints existing facilities may place on future strategies.

This research project is aimed at extending supply chain thinking so that warehouse design and operations become an integral part of planning new supply chain strategies. The project is being conducted by Peter Baker, a lecturer at Cranfield Centre for Logistics and Supply Chain Management, as part of his PhD research. Peter joined Cranfield University four years ago having previously conducted over 70 supply chain projects for a major consultancy firm and, before that, working as an office manager in international freight forwarding.

During this stage of the project, it is proposed to undertake a number of comparative case studies in major companies. A particular focus of the case study research will be how the different types of requirements for “lean” and “agile” operations are implemented.

Case study research

It is proposed to hold an initial discussion with supply chain management to understand the exact context within which the warehouses are operating. This discussion would take the form of a semi-structured interview and would be supported by an “Agility Audit”, which has been used on previous studies at Cranfield to ascertain the “lean” and “agile” characteristics of the supply chain.

During this discussion, the supply chain network would be explored and representative types of warehouse would be identified.

This would be followed by research visits to each of the representative warehouse sites. The structure of each visit would be as follows:

- Introductions and background to the research.
- Initial familiarisation with the operations (including site tour).
- Semi-structured interview with the Distribution Centre Manager to ascertain the “lean” and “agile” requirements of the distribution centre and how these are facilitated by the design and operations at the site. This would be supported by a “Warehouse Managers’ Survey” form, to place the distribution centre in the context of other warehouses that have been surveyed. Some data would be requested to measure certain aspects of the operation but the main thrust of the case study would be to understand the reasoning for different types of operation and therefore the use of quantitative data would be kept to a minimum.
- Examination of operations arising from these discussions on site.
- Review and discussion session.

As well as being of value to the research project, it is also hoped that the discussion will provide some useful “food for thought” to distribution centre managers, particularly as the results of a recent warehouse survey would be shared as part of these discussions.

Workshop

It is planned to invite all managers who have participated in the case studies to a workshop, so that they can share the initial findings of the research and discuss how each site handles the varying requirements of being part of modern supply chains. It is hoped that all participants will benefit from the findings and from this interaction. This workshop is currently planned to take place at Cranfield in early 2005.

The findings of the research will be published in academic papers, trade journals and management education programmes. Confidentiality will be respected as agreed with each company.

It is hoped that the co-operation of distribution centre professionals as part of this research will raise the profile of warehouse operations within supply chain thinking.

Supply chain agility required

	Extent	Impact
Volume variance		
Growth		
Seasonality		
Promotions		
Life cycles		
Demand variance		
Time		
Rush orders		
Small quantities		
Units vs cases vs pallets		
Presentation		
Outbound		
Information		
Customised information		
Inbound		
Volume		
Time		
Units vs cases vs pallets		
Presentation		
Information		
Returns		
Returned goods		

Extent (Scale 1 to 5; 5 = highest)

Operational response

	Current	Potential Future
Volume variance		
Growth		
Seasonality		
Promotions		
Life cycles		
Demand variance		
Time		
Rush orders		
Small quantities		
Units vs cases vs pallets		
Presentation		
Outbound		
Information		
Customised information		
Inbound		
Volume		
Time		
Units vs cases vs pallets		
Presentation		
Information		
Returns		
Returned goods		

Extent: (Scale 1 to 5; 5 = highest)

APPENDIX G: Questionnaire used to examine the role of automation
(in Paper 5)

WAREHOUSE AUTOMATION RESEARCH STUDY

All replies will be treated in the strictest confidence.

Thank you in advance for your co-operation and participation in this study. At the conclusion of the study we would like to send you an Executive Summary of the results. Please provide your name and address below.

Name: _____

Position: _____

Company: _____

Address: _____

Email: _____

General Information

1. What is your company's main area of activity

- | | |
|--|---|
| <input type="checkbox"/> Automotive | <input type="checkbox"/> Electrical, Electronics |
| <input type="checkbox"/> Food and Drink (excl. retail) | <input type="checkbox"/> Pharmaceuticals, Chemicals |
| <input type="checkbox"/> Printing, Packaging, Paper | <input type="checkbox"/> Retail |
| <input type="checkbox"/> Telecommunications | <input type="checkbox"/> Transport & Distribution |
| <input type="checkbox"/> Utilities (water, gas etc) | <input type="checkbox"/> Others (please specify) |

.....
.....

2. Who do you normally deliver your products to?

- | | |
|---|---|
| <input type="checkbox"/> Manufacturers | <input type="checkbox"/> Wholesalers / Distributors |
| <input type="checkbox"/> Retail distribution centre | <input type="checkbox"/> Stores |
| <input type="checkbox"/> Individual Customers | <input type="checkbox"/> Others (Please specify) |

.....
.....

Section One - Pre-Project

1.1 What was the prime factor or condition, which brought about the need to take action?

- | | |
|---|---|
| <input type="checkbox"/> To accommodate growth | <input type="checkbox"/> To consolidate stocks |
| <input type="checkbox"/> To improve customer service | <input type="checkbox"/> To reduce staffing level |
| <input type="checkbox"/> To reduce operating cost | <input type="checkbox"/> To improve image |
| <input type="checkbox"/> Other (please specify) | |

.....

1.2 What area of supply chain strategy did the automation project support? Please explain.

.....
.....
.....

1.3 Following the identification of a need to act, which operation(s) was (were) automated? For each of selected and specified operation(s), please name the new system/process and replaced system.

e.g. for storage operation, Narrow Aisle System is replaced by a new ASRS system.

	New	Replaced
<input type="checkbox"/> Storage
<input type="checkbox"/> Picking
<input type="checkbox"/> Sortation
<input type="checkbox"/> Material Movement
<input type="checkbox"/> Loading/unloading
<input type="checkbox"/> Others (Please Specify)		
.....
.....

1.4 If part automation, why only that particular operation was automated? Why not for related operations?

.....

1.5 How many stock keeping units (SKUs) did the warehouse stock?

.....

1.6 Who was the main sponsor within the company for the project? (e.g. Managing Director, Distribution Manager, Logistics Manager)

.....

1.7 How was the automation project executed?

- | | |
|--|--|
| <input type="checkbox"/> System Integrator | <input type="checkbox"/> Consultancy |
| <input type="checkbox"/> In-house | <input type="checkbox"/> Others (Please Specify) |
| | |

1.8 Please point out what went really well as well as badly in the pre-project period of an automation project.

.....

Section Two - During the Project

2.1 Please identify the nature of the project

- ☐ Green field site
- ☐ New system / building within existing site
- ☐ New system within existing building
- ☐ Modifications to existing systems
- ☐ Extension to existing systems / buildings

2.2 Please identify the project control mechanism for the automation project

- ☐ In house project team only
- ☐ Outside project management reporting to single in-house person
- ☐ Outside project management and in-house project team

2.3 What kind of communication structure was practised during the project?

	Daily	Weekly	Quarterly	Monthly
Top management level	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Tactical level	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Operational level	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

2.4 Status of in house people involved

	not involved	Part time	Full time
Management (e.g. logistics manager)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Operatives	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Engineers	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
IT systems	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

2.5 Degree of in-house involvement in the project during commissioning on a scale of 5, 0 being 'no involvement' and 5 the highest.

	0	1	2	3	4	5
Operational	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Maintenance	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

2.6 How did the Project Handover take place?

- ☐ Partial in planned stages ☐ Total on completion of project

2.7 What was the testing process from the supplier to the end users? Did it achieve objectives?

.....

.....

.....

2.8 Relocation of existing workforce (where relevant)

- ☐ Existing work force were trained and relocated
- ☐ Entirely new staffs were used
- ☐ Others (Please specify)
-
-

2.9 What level of communication with and involvement of the existing workforce occurred during the project? (Particularly in the case where relocation was involved)
(On a scale of 5, 0 being the lowest and 5 the highest)

	0	1	2	3	4	5
Communication	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Involvement	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

2.10 Training relating to new methods of storage, handling and management systems was performed

- ☐ In-house using equipment and systems suppliers
- ☐ Onsite using equipment and system suppliers
- ☐ Off site using equipment and systems suppliers
- ☐ Combination of above
- ☐ Others (Please explain)
-
-

2.11 What was the extent of IT changes?

	WMS	Transaction System	Equipment control System
Complete new IT system	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Modification to existing system	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Other (Please explain)

2.12 Was there any disruption to the ongoing operation to the project?

- ☐ None
- ☐ Minimal disruption
- ☐ Partial disruption
- ☐ Extensive disruption

2.13 What was the principal cause of the disruption (if any)?

- ☐ Lesser than expected
- ☐ Greater than expected
- ☐ Went according to plan

2.14 How was the disruption, stated in question 2.13 organised / managed?

- ☐ In-house
- ☐ By outside project management team
- ☐ Combination of above

2.15 Control of stock transfer from existing system to new system (if relevant)

- ☐ New stock only to new system and exhausting existing stock in existing system
- ☐ Transferring stock from old system to new one
- ☐ Others (please explain)
-

2.16 What were the key risk factors during the implementation of the project? What was done (could have been done) to mitigate the effect?

Risk	Steps taken
.....
.....
.....
.....

2.17 Please point out what went really well as well as badly during the automation project implementation.

.....

.....

.....

.....

.....

Section Three - Post Project

3.1 When did it become known if the project was a success or a failure?

- | | |
|------------------------------------|--|
| <input type="checkbox"/> 0-3months | <input type="checkbox"/> 9-12 months |
| <input type="checkbox"/> 3-6months | <input type="checkbox"/> Within 2 nd Year |
| <input type="checkbox"/> 6-9months | <input type="checkbox"/> Over 2 years |

3.2 How was the success/failure rate measured?

.....
.....

3.3 If considered partially successful would it be possible to eventually achieve the project objectives?

.....
.....

3.4 Was it carried out within the original financial budget set?

- ☐ Yes ☐ No

3.5 Was the financial planning and control successful?

- ☐ Yes ☐ No

3.6 Financial planning and control was achieved

- ☐ In-house ☐ Outside partner ☐ combination of both

3.7 Was it completed on time?

- ☐ Yes ☐ No

3.8 Please point out what went really well as well as badly during the post project period of the automation project implementation.

.....
.....
.....
.....
.....

3.9 What changes if any would you make for any other project?

.....

.....

.....

3.10 Please identify the major challenges that you faced before automation and the major challenges you anticipate over the next three years.

	Before automation	Next three years
Shorter lead time	<input type="checkbox"/>	<input type="checkbox"/>
Smaller units of picking.....	<input type="checkbox"/>	<input type="checkbox"/>
Consolidated deliveries.....	<input type="checkbox"/>	<input type="checkbox"/>
Store ready formats.....	<input type="checkbox"/>	<input type="checkbox"/>
Pre-retail activities.....	<input type="checkbox"/>	<input type="checkbox"/>
Less packaging.....	<input type="checkbox"/>	<input type="checkbox"/>
Increasing customer returns.....	<input type="checkbox"/>	<input type="checkbox"/>
Reliability of delivery times.....	<input type="checkbox"/>	<input type="checkbox"/>
Flexibility of operation.....	<input type="checkbox"/>	<input type="checkbox"/>
Short product life cycle.....	<input type="checkbox"/>	<input type="checkbox"/>
Wider SKU range.....	<input type="checkbox"/>	<input type="checkbox"/>
Inventory reduction.....	<input type="checkbox"/>	<input type="checkbox"/>
Cost reduction.....	<input type="checkbox"/>	<input type="checkbox"/>
Production postponement.....	<input type="checkbox"/>	<input type="checkbox"/>
Staff availability.....	<input type="checkbox"/>	<input type="checkbox"/>
Return packaging.....	<input type="checkbox"/>	<input type="checkbox"/>
Product recovery.....	<input type="checkbox"/>	<input type="checkbox"/>
Manual handling regulations.....	<input type="checkbox"/>	<input type="checkbox"/>
Working time directive.....	<input type="checkbox"/>	<input type="checkbox"/>
Radio frequency tags.....	<input type="checkbox"/>	<input type="checkbox"/>
System integration.....	<input type="checkbox"/>	<input type="checkbox"/>
Other (please specify).....		

3.11 Please specify any other change needed in the warehouse in order to meet the future challenge.....

.....

.....

.....

Thank you once again for completing this questionnaire.

Please **fax back** your completed questionnaire to the Centre for Logistics and Supply Chain Management, Cranfield University. **Fax: 01234 - 752441**

PUBLISHED PAPERS

1. Baker, P. (2004). Aligning distribution center operations to supply chain strategy. *International Journal of Logistics Management*, 15(1), p. 111-123.
2. Baker, P. (2007). An exploratory framework of the role of inventory and warehousing in international supply chains. *International Journal of Logistics Management*, 18(1), p.64-80.
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5. Baker, P. and Halim, Z. (2007). An exploration of warehouse automation implementations: cost, service and flexibility issues. *Supply Chain Management: An International Journal*, 12(2), p. 129-138.